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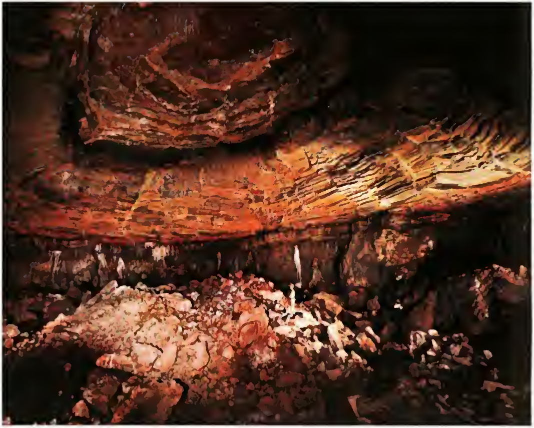
Geologic Studies
Project Gnome
Eddy County, New Mexico

GEOLOGICAL SURVEY PROFESSIONAL PAPER 589

Prepared on behalf of the
U.S. Atomic Energy Commission

US DEPARTMENT OF THE INTERIOR

GEOLOGIC STUDIES, PROJECT GNOME
EDDY COUNTY, NEW MEXICO



Cavity produced by the Gnome explosion and subsequent collapse. Note figure right-center of rubble for scale. Cavity is 70 feet high and more than 150 feet across. Photograph by Lawrence Radiation Laboratory.

Geologic Studies Project Gnome Eddy County, New Mexico

By LEONARD M. GARD, JR.

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GEOLOGIC STUDIES, PROJECT GNOME, EDDY COUNTY, NEW MEXICO

By Leonard M. Gard, Jr.

ABSTRACT

For Project Gnome, part of the Plowshare Program to develop peaceful uses for nuclear energy, a nuclear device was detonated December 10, 1961, underground in rock salt of the Permian Salado Formation southeast of Carlsbad, N. Mex.

The Geological Survey's investigations on behalf of the U.S. Atomic Energy Commission provided basic geologic and geophysical information needed to define preshot and postshot geologic and hydrologic conditions at and near the site. This report describes the geology of the site, some physical and chemical properties of the rocks, and the known effects of the nuclear detonation on the rocks of the site.

Geologic strata at the Gnome site consist of evaporite and clastic rocks of the Salado and Rustler Formations and Dewey Lake Redbeds, all of Late Permian age, the unconformably overlying Gatuna Formation of Pleistocene(?) age, and a cover of alluvial and eolian sands. All rocks, except where distorted by solution collapse, are nearly flat lying.

The evaporite deposits are easily dissolved and either are missing at the surface or only partially crop out in southeastern New Mexico; thus the sinking of a 1,200-foot shaft at Project Gnome provided an excellent opportunity to study these formations in detail. The strata were measured, sampled, and photographed while the shaft was being sunk.

The upper one-third of the Salado is exposed in the shaft and consists of 490 feet of bedded halite containing a few interstratified beds of clayey halite, anhydrite, polyhalite, and clay. The halite is overlain by a leached member comprised of 58 feet of clay, silt, gypsum, and anhydrite, much of which is a rubbly solution breccia.

The Rustler Formation disconformably overlies the Salado Formation. The five members of the Rustler are: lower member, 128 feet of silt and clay containing a few beds of gypsum; Culebra Dolomite Member, 28 feet of vesicular dolomite; Tamarisk Member, 113 feet mainly of beds of anhydrite partly hydrated to gypsum and a few thin beds of clay; Magenta Member, 21 feet of red-purple silty gypsiferous dolomite; and Forty-niner Member, 67 feet of anhydrite and gypsum.

The Dewey Lake Redbeds overlies the Rustler Formation with apparent conformity. These rocks are thinly laminated pale-reddish-brown siltstone displaying light-greenish-gray "reduction spots."

The Gatuna Formation of Pleistocene(?) age unconformably overlies the Dewey Lake Redbeds and consists of 49 feet of friable, poorly consolidated fine-grained sandstone and thin beds of clay, silt, and conglomerate. The Gatuna is in turn unconformably overlain by 43 feet of Recent alluvial bolson deposits, which are partly eolian and partly colluvial sand.

Mapping disclosed that deposition of the evaporite deposits was cyclical and resulted from repeated incursions of fresh sea water. Each cycle customarily begins with a bed of polyhalite, grades upward into pure halite, and ends with a clay-bearing halite at the base of the next higher polyhalite.

Comparison of preshot and postshot velocities in the salt near the shotpoint indicated that rock fracturing caused by the explosion was detectable from changes in elastic moduli, but compaction was not. No change in density of the rock could be detected.

The explosion formed a cavity about 70 feet high and more than 150 feet across. Postshot mining exploration revealed geologically interesting phenomena that resulted from the explosion. Intrusive breccia veins associated with complex thrust faulting were formed adjacent to the cavity. The breccia is composed of blocks of granulated and plastically deformed salt in a matrix of black melted salt. The black color of the matrix is due to the presence of laurionite, galena, and carbon. These materials, not present in the preshot rocks, were created by the shot. Lead from near the device combined with water and chlorine from salt to form laurionite and with sulfur from polyhalite to form galena. The carbon probably was derived from organic material present in the device chamber at shot time.

Lateral displacement of an instrument in a drill hole 100 feet from the shotpoint was about 16 feet. Strata 200 feet above the shotpoint were permanently displaced upward 5 feet, and a bed 55 feet below the shotpoint was displaced downward more than 10 feet.

INTRODUCTION

PURPOSE OF PROJECT GNOME

Project Gnome was a multiple-objective experiment conducted by the U.S. Atomic Energy Commission as part of the Plowshare Program to develop peaceful uses for nuclear explosives. Gnome was the first nuclear detonation within the continental limits of the United States outside of the Nevada Test Site since the Trinity shot in 1945.

The Project Gnome experiment consisted of the detonation of a nuclear device of about 3 kilotons equivalent TNT yield at a depth of about 1,200 feet below the surface in a thick salt deposit. The Gnome site is in the Nash Draw quadrangle in the approximate center of sec. 34, T. 23 S., R. 30 E., in Eddy County, and about 25 miles southeast of Carlsbad, N. Mex. (fig. 1).

The objectives of the experiment were fivefold (U.S. Atomic Energy Comm., 1961):

1. To explore the feasibility of converting the energy from a nuclear explosion into heat for the production of electric power.

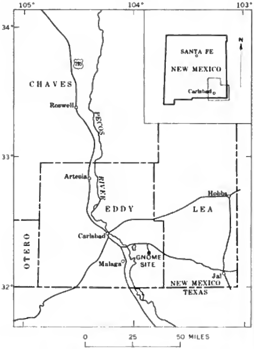


FIGURE 1.—Location of Project Gnome site, Eddy County, N. Mex.

2. To investigate the practicality of recovering useful radioisotopes for scientific and industrial applications.
3. To expand the data on characteristics of underground nuclear detonations to a new medium (salt), which differs markedly from the test media of the Nevada Test Site in which previous underground shots had been fired.
4. To make neutron cross-section measurements to contribute generally to scientific knowledge and to the reactor-development program.
5. To provide scientific and technical information on design principles useful in developing nuclear-explosive devices specifically for peaceful purposes.

HISTORICAL SUMMARY OF THE PROJECT

The Gnome shot was detonated on December 10, 1961. It was the culmination of planning and site selection that started in 1958 when a study was begun by the U.S. Geological Survey to locate a site that would satisfy both technical and public-safety requirements. The required site was to have a deposit of relatively pure salt not more than 800 feet underground, to be within the continental United States, preferably on land controlled by the U.S. Government, and to be in an area having a low population density.

The Gnome site was selected after all possible sites in the United States had been thoroughly evaluated. Subsequently, a preliminary investigation of this area was undertaken by the Geological Survey. The surface and subsurface geology of the area was studied (Baltz, 1959; Moore, 1958a, b; Cooper, 1960, 1961, 1962; Jones, 1960; Vine, 1960, 1963); the regional ground-water conditions were appraised (Hale and Clebsch, 1959); the chemical and physical properties of salt were investigated (Morey, 1958; Harry Hughes, written commun., 1959; E. C. Robertson, A. R. Robie, and K. G. Books, written commun., 1958); the seismic properties of the salt were measured and compared with those of other rock types (Byerley and others, 1960; Roller and others, 1959); and a large-scale topographic map of the Gnome site was constructed.

This report describes the geology, hydrology, and physical, chemical, and optical properties of rocks at the site.

Shaft sinking began in July 1960 and was completed to a depth of 1,200 feet in May 1961. The Gnome shaft penetrates rocks of Permian and younger age. The shaft, circular in plan, has a finished diameter of 10 feet and is lined with reinforced concrete from the surface to a depth of 722 feet. The 1,000-foot drift was mined during the summer of 1961.

PARTICIPATION BY THE U.S. GEOLOGICAL SURVEY

The U.S. Geological Survey made scientific studies and investigations related to Project Gnome on behalf of the Atomic Energy Commission. The Survey acted as agency advisor and provided technical support, largely with respect to public-safety aspects. The broad objectives of the Geological Survey's program were (1) to provide the basic geologic and geophysical information needed to define the preshot and postshot geologic and physical properties of the salt and other rocks affected by the explosion, and (2) to provide geologic and hydrologic information on the preshot and postshot hydrologic conditions at the Gnome site and surrounding region.

This report does not attempt to describe all the geologic effects produced by the Gnome explosion. Other agencies have studied close-in surface effects (Hoy and Foose, 1962) and the environment created by the explosion (Rawson, 1963; Rawson and others, 1965).

PURPOSE OF THIS REPORT

This report describes the geology of the site, some physical and chemical properties of the rocks, and the effects, as far as they are known, of the nuclear detonation on the rocks at the site. It is based on studies that were carried out between July 1960 and June 1962.

ACKNOWLEDGMENTS

For their friendly cooperation and many kindnesses, the Geological Survey personnel on the Gnome Project thank the personnel, too numerous to mention individually, of the Atomic Energy Commission; Holmes and Narver, Inc.; Lawrence Radiation Laboratory; Reynolds Electrical and Engineering Co.; and Cementation Co. of America, Inc.

METHODS OF STUDY

The rocks in the shaft were measured, described (detailed measured section, p. 24), and sampled on a noninterference basis by L. M. Gard and W. A. Mourant during construction of the shaft. This was done as final mucking after each round was completed and before drilling for the next round began. Depending on the efficiency of the blasting, a round advanced the shaft 3–6 feet.

During this construction a section of the north wall was washed down and photographed in color. Unusual geologic features noted elsewhere in the shaft wall were also photographed and described. A complete photographic log in color is available for inspection at the Field Records and Photo Library, U.S. Geological Survey in Denver.

The geology of the preshot drift (pl. 1) was mapped by L. M. Gard and C. G. Bowles, using steel tape, at a scale of 1 inch to 10 feet; vertical and horizontal control was established by Holmes and Narver, Inc. In the underground mapping, projections of both left and right ribs (walls) were used. (Left and right are identified as one faces the shotpoint.) The rib projections are rotated outward to the horizontal plane along the line that joins their bases to the sill (floor). The back (roof) was not mapped, because it displayed very few mappable geologic features.

The geology of the postshot workings (pl. 2) was mapped by L. M. Gard and W. L. Emerick, assisted by W. H. Laraway, M. L. Schroeder, and John Moreland, Jr. The method was the same as that used in preshot mapping except that near the cavity, to expedite the work because of time limitations, the ribs were mapped continuously. Thus, the nine walls of the drilling alcove and parts of the approaching drift are represented by a single straight projection, and the corners are indicated for clarity in map presentation. Although the preshot drift was intact after the shot, it was not remapped because of high levels of radiation.

Prior to mapping both the preshot, and the postshot workings, the ribs were washed with water. The cleaned wet rock displayed additional stratigraphic details.

Elastic properties of the salt were determined underground, both before and after the shot, by D. D. Dickey and D. R. Cunningham. Preshot calculations were made by R. D. Carroll and D. D. Dickey, and postshot calculations were made by D. D. Dickey.

From his knowledge of the minor-element content in evaporite rocks of southeastern New Mexico, C. G. Bowles suggested and later supervised the determination of the minor elements in the salt beds of the preshot drift. B. M. Madsen made the petrographic descriptions of the preshot samples, Julius Schlocker studied the insoluble clastic material from these samples, and Theodore Botinelly determined the composition of the intrusive breccia formed by the explosion.

GEOLOGY

REGIONAL SETTING

The Gnome site is on the Mescalero pediment on the east side of the Pecos Valley, a section of the Great Plains physiographic province (Fenneman, 1931, fig. 1). The Pecos River flows through the southwestern part of this section and divides it physiographically into the Mescalero pediment to the east and the alluvial plain north of Malaga and the Gypsum Hills south of Malaga to the west.

The Gnome site is in the northeastern part of the Deleware basin (Adams, 1944; King, 1948; Newell and others, 1953). This deep structural basin, which is about 135 miles long and 75 miles wide, lies in southeastern New Mexico and west Texas and is generally considered to be the area surrounded by the Capitan Limestone (a reef limestone of Late and Early Permian age). The Capitan reef is horseshoe shaped, opening southward, and extends in the subsurface from Carlsbad eastward nearly to Hobbs, N. Mex., and thence southeastward into Texas (fig. 2). West and southwest of Carlsbad the Capitan Limestone is exposed and forms El Capitan Peak and part of the Guadalupe Mountains. Large caverns—notably Carlsbad Caverns—were formed in the reef limestone through the solvent action of circulating ground water.

The Delaware basin was submerged in Permian time (230–280 million years ago, according to Kulp (1961)) and was filled with thousands of feet of sediment. Toward the end of Permian deposition in the basin, the

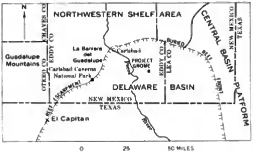


FIGURE 2.—Extent of the Delaware basin in New Mexico and adjacent structural and geographic features. Modified from King (1948) and Stipp and Haigler (1956).

reef growth around the basin was halted by increasing salinity of the sea water, and the evaporite rocks of the Castile, Salado, and Rustler Formations were deposited.

The Salado Formation, almost wholly salt, was deposited in a sea that extended from the Delaware basin across the Capitan reef zone many miles onto the shelf to the north. The southern end of this sea apparently had a restricted opening, and the consequent reduced circulation and outflow allowed evaporation to concentrate the sea water therein until salt was precipitated on the floor of the basin in southeastern New Mexico. The concentrated brine undoubtedly was replenished periodically by normal sea water; otherwise, the process would soon have ceased as the basin dried up. The salt beds of the Salado Formation grade southward into calcium sulfate and then into calcium carbonate facies, suggesting that the source of normal sea water lay in that direction and that the water became more concentrated as it moved northward.

After deposition of the evaporite rocks ceased, deposition of fine-grained terrestrial clastic sediment (Dewey Lake Redbeds) marked the close of the Permian. Terrestrial deposition continued during parts of Triassic time (181–230 million years ago), although subsequent erosion has removed Triassic beds from the Gnome area. Additional thin sediments accumulated in Quaternary time.

The evaporite rocks in the Delaware basin contain extensive deposits of potash minerals, which are mined at many localities. Many wells produce oil from the reef limestone in southeastern New Mexico and west Texas. Oil and gas are produced also from some of the deeper formations in the Delaware basin.

GNOME AREA

The Gnome area referred to in this report is the square mile of sec. 34, T. 23 S., R. 30 E. (fig. 3). The land surface at the area is covered with as much as 43 feet of alluvial and windblown sand and caliche. More than 18,000 feet of sedimentary material ranging in age from Ordovician to recent underlies the Gnome site. Beneath the surface lie, in descending order, the Gatuna Formation of Pleistocene(?) age, the Dewey Lake Redbeds, and the Rustler and Salado Formations of Late Permian age. Beneath the Salado are thousands of feet of Paleozoic rocks which are not discussed in this report. All these formations are concealed by alluvium in the Gnome area, but all except the Salado crop out nearby (Vine, 1963).

Solution by ground water of salt at the top of the Salado Formation and of anhydrite within the Rustler Formation has removed thick sections of these rocks. A subsequent lowering of the land surface and differential collapse of the Rustler have formed many sinkholes and created a karst topography over much of this part of southeastern New Mexico. Nash Draw, about 6 miles to the northwest, is one of the largest depressions. Within Nash Draw are several smaller depressions, the largest of which is Laguna Grande de la Sal (Salt Lake).

The rocks dip gently to the east and southeast, and progressively younger formations are exposed in that

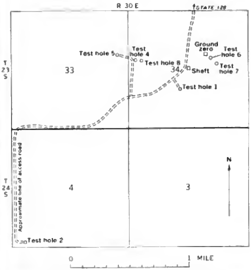


FIGURE 3.—Location of shaft, ground zero, and U.S. Geological Survey test holes at Project Gnome site.

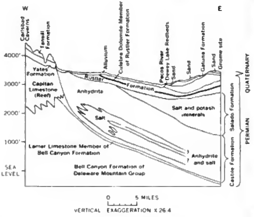


FIGURE 4.—Geologic section between Carlsbad Caverns National Park and Project Gnome site. Modified from Cooper (1960).

direction (fig. 4). Although the Salado Formation underlies an extensive area in southeastern New Mexico, no outcrops of it are known.

In many places the salt of the Salado Formation has been wholly or partially removed by solution. West of the Pecos River, very little salt remains; to the northwest over the buried Capitan reef, no salt is present; and south of the Gnome site, the Saldo salt is thin or absent over an area of nearly 100 square miles (Cooper, 1962). As much as 800 feet of salt has been removed. Within Nash Draw, solution has removed, and is presently removing, salt from the upper part of the Salado Formation.

The Rustler Formation crops out in numerous places west and northwest of the Gnome area and south of Malaga, a small town about 10 miles west of the area. The Dewey Lake Redbeds is exposed at several localities north and west of the Gnome area, especially along the margin of Nash Draw, and also crops out in a narrow discontinuous north-south belt a few miles east of the Pecos River. Triassic rocks are represented by the Santa Rosa Sandstone north of Nash Draw and southeast of the area; the Santa Rosa is not present, however, at the Gnome site. Unconsolidated Tertiary rocks crop out east of the area.

Quaternary rocks include the Gatuna Formation of Pleistocene(?) age, and alluvium, windblown sand, caliche, and playa lake deposits of Recent age. Alluvium occurs chiefly near the Pecos River north of Malaga. A recent report by Vine (1963) includes a geologic map of the Nash Draw quadrangle and stratigraphic sections of exposed rocks. The following generalized stratigraphic section (table 1) describes the rocks exposed in the Gnome shaft (fig. 5).

TABLE 1.—*Generalized stratigraphic section of rocks exposed in the Gnome shaft*

Age	Unit	Lithology	Depth below surface (ft)	Thickness (ft)
Recent..........	Alluvial bolson deposits.	Unconsolidated sand.	0 – 43	43.0
Pleistocene(?)...	Gatuna Formation.	Friable sandstone and conglomerate.	43 – 91.9	48.9
Late Permian...	Dewey Lake Redbeds.	Thin-bedded siltstone.	91.9–294	202.1
	Rustler Formation;			
	Forty-niner Member.	Chiefly gypsum and anhydrite.	294 –361.3	67.3
	Magenta Member.	Silty dolomite....	361.3–382.2	20.9
	Tamarisk Member.	Chiefly anhydrite and gypsum.	382.2–495.5	113.3
	Culebra Dolomite Member.	Dolomite.........	495.5–523.5	28.0
	Lower member.	Chiefly clay and silt, with some gypsum and anhydrite.	523.5–651.2	127.7
	Salado Formation:			
	Leached member.	Chiefly claystone and siltstone.	651.2–709.2	58.1
	Unleached part.	Chiefly impure halite rock, with some anhydrite, polyhalite, and siltstone.	709.3–1,202	492.7
	(Bottom of shaft.)			

Structural deformation of the rocks is limited mainly to a gentle monocline in the Permian rocks and to collapse structures in the evaporite sections of the Permian rocks. No deeply buried faults are known. Locally, there are structural features related to the hydration of anhydrite to gypsum. This hydration considerably increased the volume of the affected rocks and caused them to be deformed, and in many places domed, where they are exposed at the surface (Vine, 1960).

STRATIGRAPHY AT THE SITE

The following stratigraphic descriptions are supplemented by the detailed measured section at the end of the report (p. 24).

SALADO FORMATION

At the Gnome site the Salado Formation is about 1,550 feet thick. More than 75 percent of the thickness of the Salado is salt, except where solution has thinned the formation. The remainder of the formation consists of potassium minerals and minor amounts of sandstone, siltstone, shale, anhydrite, and gypsum.

The bulk of the Salado is not known to contain ground water, although the leached member at the top of the formation is a brine aquifer locally. No free water has been reported to occur within the formation in the potash mines nor in the many drill holes throughout the

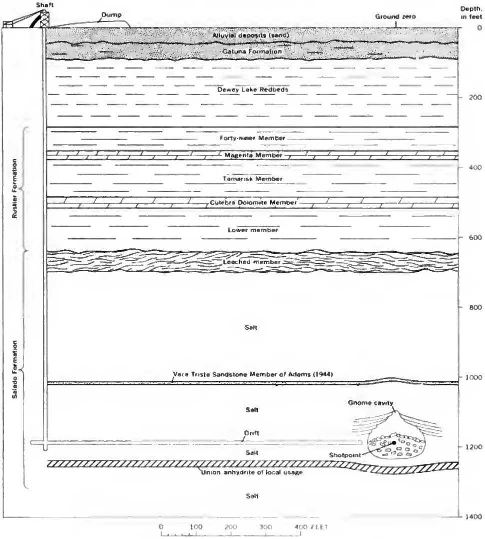


FIGURE 5.—Geologic cross section between shaft and cavity, Project Gnome site.

area. The halite rock is virtually impermeable because recrystallization of the salt restricts migrating fluids and prevents the formation of open spaces.

The shaft penetrated more than 490 feet of bedded halite that contains minor interstratified beds of clayey halite, anhydrite, polyhalite, and clay. The halite beds range in color from transparent colorless through white to reddish orange. The intensity of the orange color depends upon the amount of disseminated iron and polyhalite impurities present. The clayey halite beds range in color from reddish brown to greenish gray. The reddish-brown polyhalite beds, locally used as marker beds, average about 1 foot thick. They commonly have a thin bed of greenish-gray clay at the base. From 1,024.3 to 1,029 feet the shaft cut the Vaca Triste Sandstone Member of Adams (1944), a pale-reddish-brown clayey siltstone that forms a well-known marker unit.

The total thickness of the Salado Formation at the Gnome site has not been determined accurately, but data from nearby oil tests indicate that as much as 1,550 feet of the formation may be present (fig. 4).

The uppermost 58 feet of the Salado Formation consists of reddish-brown to gray clay and silt with a few interstratified gypsum and anhydrite beds. These strata represent, at least in part, an insoluble residue left after the removal of halite by ground water. This leached member or zone is estimated to be roughly one-third to one-tenth the thickness of the original halite rock that was present. The thickest unit of this leached zone is a solution breccia 36 feet thick. It is a heterogeneous rubbly mixture composed of siltstone, gypsum, and polyhalite blocks as much as 3 feet long set in a matrix of plastic grayish-red clay. In the shaft the leached zone did not contain water, although a small amount of water was detected in this zone in an observation well drilled about three-fourths mile west of ground zero (Gard and others, 1962, p. 121). Vine (1963, p. 8) reported that locally the leached zone is a prolific aquifer.

The top of the Salado Formation is considered by many geologists to be at the top of the uppermost halite bed, and the leached member is assigned to the Rustler Formation. This assignment is based partly on the fact that the Rustler Formation is reported to contain some salt beds to the southeast, and partly on the fact that the leached member cannot be distinguished from the lower member of the Rustler in either drill cuttings or geophysical logs. However, because the leached member was recognized as a distinct unit in the Gnome shaft and because it has a disconformable upper contact and contains several collapse breccia beds that are distinctly different from the lower member of the Rustler, it has been assigned in this report to the Salado Formation.

RUSTLER FORMATION

The Rustler Formation of Late Permian age unconformably overlies the Salado Formation and is composed mainly of evaporite deposits of anhydrite (commonly altered to gypsum) and dolomite and contains some siltstone and clay in the lower part. The thickness of the Rustler at the shaft is 357.2 feet, although in nearby areas the thickness ranges from 90 to more than 500 feet.

The Rustler is divided into five members, all present in the Gnome shaft. The upper four members crop out near Nash Draw to the north and near the Pecos River to the west.

The lower, unnamed member of the Rustler Formation lies disconformably on the leached top of the Salado Formation. It is 127.7 feet thick and consists principally of poorly consolidated silt and clay and contains a few interstratified beds of gypsum.

The Culebra Dolomite Member overlies the lower member and consists of 28 feet of yellowish-gray generally microcrystalline dolomite. It contains some massive zones, as well as as brecciated zones, that are recemented with pale-yellowish-brown dolomite. A characteristic feature of the Culebra is the presence of numerous small nearly spherical cavities that range from 1 to 20 mm in diameter. Some cavities are partly filled with secondary gypsum and calcite, but most are open. They do not appear to be interconnected. These cavities are thought to have originated either by solution of a highly soluble mineral aggregate or by the inclusion of gas or liquid when the sediment was soft (Vine, 1963, p. 14).

The Culebra Member is an artesian aquifer at the shaft, where it has a head of about 75 feet. The water appears to be contained in fractures and is confined above by the anhydrite and gypsum of the Tamarisk Member and below by clay of the lower member.

The Culebra is an excellent subsurface marker, because its lithology is unique in southeastern New Mexico. It is widespread in the Delaware basin and has been identified in many hundreds of drill holes. It is the principal aquifer at the Gnome site and yields water to wells in the western half of the project area. The depth to the top of the Culebra ranges from zero in the Nash Draw–Pecos River area to at least 1,200 feet in the eastern part of the State. The configuration of the top of the Culebra is similar to that of the top of the salt in the Salado Formation. Apparently, as salt in the Salado was removed by solution, the overlying beds settled and assumed, in general, the shape of the surface of the remaining salt.

The overlying Tamarisk Member is 113.3 feet thick and is composed mainly of beds of anhydrite partly hydrated to gypsum, but it contains some thin beds of clay.

The overlying Magenta Member is a red-purple (magenta) silty gypsiferous dolomite 20.9 feet thick. Although an aquifer in some places, it contains no water at the shaft.

The Forty-niner Member, like the Tamarisk Member, is composed mainly of anhydrite and gypsum. It is 67.3 feet thick in the shaft, but is missing in U.S. Geological Survey hydrologic test holes 4 and 5 about one-half mile west of the shaft (fig. 3). Whether removal of the Forty-niner Member was by erosion prior to deposition of the Dewey Lake Redbeds or by leaching subsequent to deposition is not known, although leaching is considered to be more likely.

The structure of the Rustler Formation is mildly undulating where these beds are 200–300 feet below the ground surface. Locally, however, solution and collapse have affected the formation where it is deeply buried. Generally the carbonate members—the Culebra and the Magenta—are the least affected by solution and are present throughout most of the area. At the Gnome site they are separated by more than 100 feet of the Tamarisk Member. In the Nash Draw area, solution and collapse have locally removed the entire Tamarisk, and the Magenta rests directly upon the Culebra.

DEWEY LAKE REDBEDS

The Dewey Lake Redbeds of Late Permian age overlies the Rustler Formation with apparent conformity. The contact is marked by the abrupt color change from the white of the gypsum of the Forty-niner Member of the Rustler Formation to the red of the Dewey Lake.

The Dewey Lake is mainly made up of pale-reddish-brown siltstone that displays a polka-dot appearance, owing to the presence of light-greenish-gray reduction spots (round spots about 0.5 cm across where ferric iron has been reduced to ferrous iron). The formation is 202.1 feet thick in the shaft and is composed mainly of subangular to subrounded clear quartz grains and chert and feldspar grains in a clay matrix. Muscovite, biotite, rock fragments, and opaque minerals make up less than 10 percent of the mineral grains. Bedding consists of thin (0.5–1.5 mm) laminae and, less commonly, very small scale cross-laminations. Red clay forms 15–25 percent of the rock and is the principal cement, although calcite and gypsum are common. The Dewey Lake represents the beginning of detrital sedimentation following the long period of chiefly evaporite deposition in the Delaware basin and adjacent shelf areas in southeastern New Mexico.

GATUNA FORMATION

The Gatuna Formation of Pleistocene(?) age unconformably overlies the Dewey Lake Redbeds and is pale-red to moderate-brown friable fine-grained sandstone, 48.9 feet thick in the shaft, that contains a few thin beds of clay and silt and many thin beds of conglomerate. The sand- and silt-sized material is mainly made up of quartz grains, and the pebbles are quartzite, limestone, and chert. The grains are weakly to moderately cemented with calcium carbonate. The presence, in several beds, of reworked fragments from the underlying Dewey Lake suggests that the Gatuna was deposited on a surface of considerable relief.

Elsewhere in the Nash Draw quadrangle (Vine, 1963), the Santa Rosa Sandstone of Triassic age lies between the Dewey Lake Redbeds and the Gatuna Formation, but it is missing at the Gnome site.

ALLUVIAL BOLSON DEPOSITS

Alluvial bolson deposits of Recent age unconformably overlie the Gatuna Formation and are chiefly made up of unconsolidated moderate-brown fine-to medium-grained quartz sand. The upper 9 feet of these deposits is dune sand, but the lower 34 feet is partly eolian and partly colluvial. The sand has been derived from the Gatuna Formation and perhaps in part from the Ogallala Formation of Pliocene age, which may once have covered the area (Vine, 1963, p. 36). The top 3 feet of the lower 34 feet is weakly cemented by caliche, a near-surface accumulation of calcareous material, that was precipitated by subsurface evaporation of moisture in this semiarid region.

STRUCTURE

The rocks penetrated by the shaft are nearly flat lying, although locally in the shaft the Rustler Formation dips steeply. The regional structure is a small homoclinal dip to the east (Vine, 1963, p. 37). In the shaft the Dewey Lake rocks strike N. 45° E. and dip about 5° NW. Bedding in the Salado Formation observed in the drift strikes N. 89° E. and dips 0°20′ N. The attitude of the bedding in the Salado Formation is locally variable. Information from a drill hole 500 feet south of ground zero suggests that the same beds may be as much as 10 feet higher in the drill hole than in the drift. Whether this difference is due to a local flexure or to an error in drilling observations is not known.

Fairly steep dips were observed in some beds of the Rustler Formation, especially in gypsum and anhydrite. Dips as high as 42° NW. were noted in a gypsum bed in the lower member of the Rustler. These anomalous attitudes are believed to be associated with volume changes that take place when anhydrite changes to gypsum or when solution differentially telescopes the rocks. The northwest dip observed in the Dewey Lake Redbeds may result from thinning of the underlying Rustler Formation to the west or northwest. As previously noted, the Forty-niner Member of the Rustler is completely missing in test holes drilled about half a mile west of the shaft.

GEOLOGY OF THE PRESHOT GNOME DRIFT

The nuclear device was placed in a small chamber at the end of a drift (pl. 1) driven N. 50° E. from the bottom of the shaft. The drift was 1,223 feet long and included a curved section near the shaft. The end of the drift curved around a "buttonhook," doubling back on itself and ending at the device chamber. The device chamber was about 1,000 feet horizontally from the bottom of the shaft and slightly less than 1,200 feet below the ground surface. Thus, the rock cover over the detonation point consisted of about 500 feet of massive salt beds and about 700 feet of other sedimentary rocks. Below the detonation point was probably an additional 1,000 feet of bedded salt.

Only the Salado Formation is exposed in the drift; bedding strikes N. 89° E. and dips 0°20′ N. Owing to the low dips, the ribs (walls) of the drift were mapped to show geologic features that could not be included on an ordinary map (pl. 1). Mapping, done during July 1961, was on a scale of 1 inch to 10 feet to show the depositional features in the salt strata in some detail.

Eight mappable beds of halite rock containing varying amounts of clay and polyhalite and one mappable bed of polyhalite were transected by the drift. The nine beds were arbitrarily numbered in descending order from 10 to 18. Because the drift intersects the bedding at an angle of about 40° to the strike, the beds have a component of dip toward the device chamber; thus, the lowest beds are exposed near the shaft, and successively higher beds are exposed toward the device chamber. Total thickness of the exposed beds is about 22 feet. The following stratigraphic section (table 2) describes the beds in the Gnome drift.

Deposition of the Salado Formation was often cyclic, as indicated by the strata exposed in the drift. Ideally, a cycle begins with a polyhalite bed at the base, grades upward into halite containing polyhalite, and terminates with clay-bearing halite at the top. A cycle represents an incursion of fresh sea water that temporarily decreased the salinity of the brine and caused deposition of calcium sulfate. Concentration of the fresher sea water subsequently caused the precipitation of sodium chloride.

TABLE 2.—*Detailed stratigraphic section of Salado Formation along drift from device chamber to shaft*

Unit	*Description*	*Thickness (ft)*
120	Polyhalite rock (marker bed 120), reddish-brown, microcystalline; varies in thickness because upper contact gradational into overlying halite. (Exposed in postshot workings.)	0.5–1.5
10	Halite rock, colorless to pale-orange; grain size 10–20 mm; bands 0.25–0.3 ft thick of colorless to milky halite alternate with 0.1- to 0.2-ft-thick bands of pale-orange halite containing disseminated orange polyhalite; 0.18-ft thick discontinuous band of orange polyhalite 1.2 ft below top of unit; polyhalite more concentrated in lower 1.5 ft; dark-gray clay layer 5.4 ft above base (clay seam in fig. 12); lower 0.8 ft contains 4 percent gray clay in thin horizontal streaks and bands; device set at base of this unit. (Only lower 4.3 ft exposed in preshot drift.)	8.0
11	Halite rock, clear, gray, rarely brown, gray clay seam 0.05 ft thick at top; contains a few discontinuous bands of halite with disseminated polyhalite; displays ripple-mark casts where back of drift breaks to base of unit	.2–1.0
12	Halite rock, light-gray to light-brown; clay content 10–50 percent; clay generally brown but some gray; base of unit a brown clay seam which at places truncates upturned beds of underlying unit	.2–1.0
13	Halite rock; contains inclusions of brown clay, upper 2 ft contains irregular layers of brown clayey halite alternating with pale-orange to grayish-white halite; contains vertical mudcracks filled with clay, polyhalite, and secondary halite; layers between mudcracks near top of unit are concave upward; lower 1.5 ft light-brown halite with 20–25 percent inclusions and vertical streaks of brown clay; clay content decreases downward; contact with underlying unit gradational	3.5
14	Halite rock, pale-orange to white; contains blebs and disseminated particles of orange polyhalite forming indistinct layers which are most noticeable in lower half	3.5–4.0
15	Polyhalite rock (marker bed 121), moderate-reddish-brown, microcrystalline; variable thickness usually due to irregularity of upper contract, which may be gradational; lower contact sharp	.5–1.0
16	Halite rock, colorless to gray-green to pale-orange; 0.1 ft greenish-gray clay at top; upper 1.6 ft contains 20 percent gray-green clay and 3 percent polyhalite; clay content decreases downward; upper part contains pods and downward-tapering wedges of secondary halite containing gray-green clay and polyhalite	4.8
17	Halite rock, colorless to light brown; 10 percent streaks and inclusions of brown clay. (Exposed only in blast-door alcove)	.5
18	Halite rock, colorless to light-brown; contains 2 percent brown clay and 2 percent polyhalite. (Exposed only in blast-door alcove.) Base not exposed	3+
	Total exposed thickness	22+

One complete cycle of deposition and parts of two others are represented in the drift. The complete cycle began with the deposition of unit 15, the polyhalite bed, and ceased with the deposition of unit 13. Units 16–18 are part of the previous cycle, and units 10–12 are part of the subsequent cycle.

Polyhalite probably was not deposited from the original brine but was altered from gypsum or anhydrite

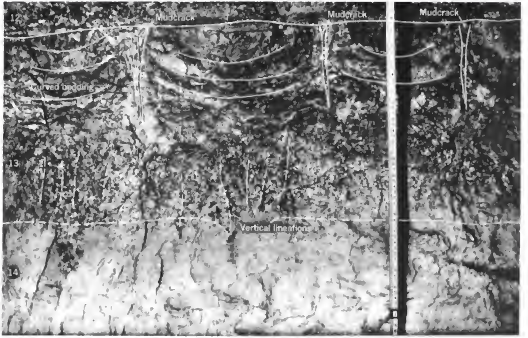


FIGURE 6.—Units 12, 13, and 14 exposed in preshot drift. Note mudcracks in unit 13 with curved bedding between, and vertical lineations at base of unit 13.

by the later addition of potassium and magnesium (Moore, 1958b, p. 14).

The polyhalite bed (unit 15), known locally as marker bed 121, is present in the Salado Formation over a wide area. Its sharp regular lower contact is underlain by a thin layer of greenish-gray clay. Thin clay layers underlie many of the polyhalite beds in the Salado Formation and are thought to have been concentrated by the re-solution of impure salt when the brine was freshened.

In places along the drift the polyhalite is underlain by pods of abnormally large halite crystals which contain disseminated gray clay and polyhalite. Whenever the pods are present, the underclay is absent. The gross halite crystals in these pods are thought to have resulted from secondary recrystallization.

Continued concentration of the brine by evaporation resulted in deposition of unit 14, which contains little or no clay but contains polyhalite blebs. Unit 14 is gradational upward into unit 13, which contains as much as 25 percent clay. Further evaporation, perhaps even to dryness, produced desiccation cracks in unit 13 (fig. 6). These cracks are filled with clay, halite, and polyhalite. In the upper part of this unit, bedding between the desiccation cracks is concave upward and resembles the cross section of curved polygonal plates that commonly develop between desiccation cracks. Most of these features were seen only in cross section; one polygonal structure, however, is well exposed in the back of the drift at station 4+35 and exhibits a typical 120° junction of three mud-filled cracks, one of which is traceable down the right rib. Another such junction is well exposed in the No. 12 lateral in the reentry drift. Probably this part of the basin either was evaporated to dryness or was locally uplifted to above sea level at this time. Desiccation cracks observed at several places in the shaft and in the core from a hole drilled at ground zero indicate recurrent complete evaporation during deposition of the Salado Formation. These cracks could, however, represent a time of local upwarp and subaerial exposure of a limited area rather than evaporation to dryness of the entire basin.

The clay in unit 13, which decreases downward, displays faint vertical brown clayey lineations, which may have been caused by downward percolation of rain water, if salt strata were exposed by local upwarp, or by sea water when the area was again submerged. This vertical lineation is clearly visible in figure 6.

Units 11 and 12 are very thin, aggregating generally less than a foot in thickness, and are separable only by the difference in color of their contained clay. Unit 11 is generally gray, and unit 12 is generally brown. The top of unit 12 and the bottom of unit 11 display current ripple marks in the back of the drift near station 5+45 where the underside of unit 12 is exposed in the back of the drift. The contact between units 12 and 13 is very sharp, and some of the upturned beds at the top of unit 13 appear to have been truncated by unit 12.

Precipitation of salt began again with the formation of unit 12; the brine was apparently concentrated enough so that sodium chloride was the first mineral deposited. In unit 10 alternating layers of colorless halite and orange halite (colored from the iron in disseminated polyhalite) suggest rhythmical freshening of the brine. The top bed of this cycle seen in the postshot workings and cavity walls is a polyhalite bed (marker bed 120) that lies only a few feet above unit 10 and indicates the beginning of a new depositional cycle.

PROPERTIES OF THE ROCKS

To define the rocks surrounding and overlying the device chamber various properties were determined, both before and after the shot. Certain physical properties were determined both in the laboratory and in situ. Semiquantitative spectrographic analyses were made, and the petrography of the rocks exposed in the drift was studied.

These preshot determinations were made to provide a basis for postshot comparisons. It was found, however, that the shot had little effect on the bulk of the geologic medium, and, accordingly, detailed postshot analyses were made only in specific places on rocks close to the cavity.

PHYSICAL PROPERTIES

Various physical properties were determined by the Geological Survey laboratories for 32 samples (tables 3, 4) collected from the Gnome shaft during construction. These samples are considered to be representative of the rocks overlying the device chamber.

Porosity, grain density, and dry-bulk density of the insoluble samples were determined by the water-saturation, mercury-displacement, and powder-grain methods. For water-soluble samples, kerosene was substituted for water, and the proper density corrections were made (table 3).

Dynamic elastic moduli were determined from calculations using torsional and flexural resonant frequencies of specimens (table 3). Static elastic moduli and compressive strength were measured on cores 1 inch in diameter and 2 inches long (table 4).

TABLE 3.—*Physical properties of rock samples from Gnome shaft*

[Analysts: D. R. Cunningham, John Moreland, Jr., and E. F. Monk. Asterisk (*) indicates 10^6 psi (pounds per square inch); nd, not determined; . . ., not determined owing to insufficient sample]

Geologic unit	Lithology	Depth (ft)	Porosity (percent)	Grain density (g per cc)	Dry-bulk density (g per cc)	Magnetic susceptibility (10^{-6} cgs units) air dried	Sonic method				
							Young's modulus (10^6 psi)	Modulus rigidity (10^6 psi)	Poisson's ratio	Longitudinal velocity (ft per sec)	Transverse velocity (ft per sec)
Gatuna Formation	Sandstone	50- 70	31.9	2.66	1.81	36.9	*5.38	*2.64	0.9189	5,072	3,552
Dewey Lake Redbeds	Siltstone	96- 100	21.6	2.68	2.10	7.5	nd	nd	nd	nd	nd
	do	250	11.8	2.65	2.36	10.8	nd	nd	nd	nd	nd
Rustler Formation:											
Forty-niner Member.	Anhydrite	298	7.9	2.50	2.31	5.3	2.56	1.09	.1743	10,825	6,816
	do	320	12.2	2.82	2.48	6.6	2.19	1.30	.2269	10,223	6,976
	Siltstone	331	24.8	2.66	2.00	14.9	1.18	*5.34	.1028	6,836	4,548
	Gypsum	343	8.7	2.43	2.22	6.7	2.66	1.27	.0472	10,715	7,386
	Gypsum and anhydrite	350	3.6	2.37	2.29	2.6	2.52	1.00	.2600	11,275	6,421
Magenta Member	Dolomite	365	34.7	2.92	1.91	4.9	*7.10	*2.85	.2456	5,567	3,244
	Dolomitic siltstone	370	22.7	2.81	2.17	7.9	nd	nd	nd	nd	nd
	Dolomite	380	19.1	2.91	2.35	4.1	nd	nd	nd	nd	nd
Tamarisk Member	Gypsum and anhydrite.	400	2.5	2.39	2.33	4.3	5.41	2.29	.1812	16,208	9,487
	Claystone	482	22.1	2.68	2.06	6.2	*9.39	*3.71	.2655	6,546	3,713
Culebra Dolomite Member.	Dolomite	505	12.5	2.85	2.49	3.8	nd	nd	nd	nd	nd
	do	515	12.3	2.83	2.48	2.1	2.96	1.28	.1563	6,809	6,261
Lower member	Claystone	527	29.6	2.71	1.91	10.5	nd	nd	nd	nd	nd
	Gypsum and anhydrite	535	2.1	2.37	2.3	4.5	2.93	1.13	.2965	12,706	6,834
	Claystone	552	25.1	2.68	2.01	6.2	*8.41	*3.40	.2368	6,201	3,642
	Siltstone	590	21.3	2.71	2.13	10.1	1.34	*5.98	.1167	7,044	4,640
	do	620	19.3	2.70	2.17	7.7	nd	nd	nd	nd	nd
Salado Formation	Claystone breccia (residuum).	653	26.2	2.68	1.98	17.2	nd	nd	nd	nd	nd
	Siltstone (residuum)	693	1.1	2.15	2.13	5.9	1.40	*6.67	.0526	7,367	5,062
	Anhydrite (residuum)	700	2.7	2.52	2.45	4.6	1.86	*7.04	.3219	9,064	4,653
	Halite	715	2.7	2.16	2.11	2.2	. . .	. . .	. . .	. . .	. . .
	do	720- 725	1.1	2.49	2.46	4.3	. . .	. . .	. . .	. . .	. . .
	do	1,013-1,015	5.1	2.24	2.13	3.7	. . .	. . .	. . .	. . .	. . .
	do	1,019-1,023	1.2	2.27	2.24	6.7	. . .	. . .	. . .	. . .	. . .
	do	1,120-1,123	7.1	2.33	2.17	12.1	. . .	. . .	. . .	. . .	. . .
	do	1,130	1.7	2.18	2.14	9.3	. . .	. . .	. . .	. . .	. . .
	do	1,147-1,152	.8	2.18	2.16	7.8	. . .	. . .	. . .	. . .	. . .
	do	1,173-1,178	2.2	2.15	2.09	6.3	. . .	. . .	. . .	. . .	. . .
	do	1,177-1,181	2.7	2.38	2.31	5.4	. . .	. . .	. . .	. . .	. . .

TABLE 4.—*Physical properties of rock samples from Gnome shaft, as determined by static method*

[Analysts: T. C. Nichols, J. C. Thomas, and R. A. Speirer]

Lab. No. P1-	Depth (ft)	Lithology of sample	Condition of sample	Description	Unconfined compressive strength (psi)	Secant Young's modulus (psi)	Secant range (psi)	Poisson's ratio	Shore hardness	Remarks
102	320	Anhydrite..	Good....	Lineation of gypsum-filled fractures approximately 70° to platens. Length, 3.0 in.; diameter, 1.470 in.; parallelism, .0012 in. Oven dried.	3,900	2.86×10^6	300-1400	0.19	24	Loading: Longitudinal strain, first cycle; latitudinal strain, second cycle. Failure occurred along fracture planes.
104	343	Gypsum....	do.....	Both ends slightly chipped. No lineation. Length, 2.078 in.; diameter, 1.0 in.; parallelism, <.001 in. Oven dried.	3,180	3.18×10^6	300-1300	.10	12	Loading: Longitudinal strain, first cycle; latitudinal strain, second cycle; compressive strength, third cycle.
109a	400	Anhydrite and gypsum.	Fair.....	No fractures. One end of core chipped. Length, 2.716 in.; diameter, 1.438 in.; parallelism, .0009 in. Oven dried	2,400	2.2×10^6	300-1400	.23	...	Loading: Longitudinal strain, first cycle; latitudinal strain, second cycle.
109b	400	do.....	Poor.....	Many gypsum-filled fractures normal to platens. Length, 2.078 in.; diameter, 1.0 in.; parallelism, <.001 in. Oven dried.	8,900	1.14×10^6	300-1600	.10	7	Loading: Longitudinal strain, first cycle; latitudinal strain, second cycle. Both extension and shear fractures occurred along gypsum planes during failure.
112	515	Dolomite....	Good....	A few weathered holes. No lineation. Length, 2.031 in.; diameter, 1.0 in.; parallelism, <.001 in. Oven dried.	12,700	4.31×10^6	300-2500	.27	17	Loading: Longitudinal strain, first cycle; latitudinal strain, second cycle; compressive strength, third cycle.
116	693	Siltstone..	Fair....	Several fractures. One end chipped. No lineation. Length, 4.063 in.; diameter, 2.109 in.; parallelism, .0048 in. Oven dried.	6,200	1.14×10^6	600-2300	.31	13	Only one cycle of loading.
120	700	Andydrite..	Good....	A small chip on one end. Lineation approximately parallel to platens. Length, 4.10 in.; diameter, 2.109 in.; parallelism, .0019 in. Oven dried.	3,200	2.97×10^6	600-1700	.42	19	Only one cycle of loading. Failure occurred along planes normal to lineation.

The hardness of the rocks (table 4) was measured on a Shore scleroscope. This instrument utilized a diamond-tipped hammer, which is raised to a standard height above the rock specimen and then dropped onto it. The height of the rebound is proportional to hardness and is recorded on a scale of 0 to 120.

Porosity of rocks above the salt ranges from as high as 34.7 percent for the Magenta Member of the Rustler Formation to as low as 1.1 percent for siltstone residuum at the top of the Salado Formation. Porosity of halite from the Salado ranges from 7.1 percent to 0.8 percent. Grain density ranges from 2.92 g per cc (grams per cubic centimeter) for the Magenta to 2.15 g per cc for the same siltstone residuum at the top of the Salado. Grain density of the halite ranges from 2.49 to 2.15 g per cc. Dry-bulk density ranges from a high of 2.49 g per cc in the Culebra Member of the Rustler Formation to a low of 1.81 g per cc in the Gatuna Formation. Dry-bulk density of the halite in the Salado ranges from 2.46 to 2.09 g per cc.

Sonic velocities were determined in the laboratory for rocks overlying the Salado Formation. Longitudinal velocities range from 15,205 fps (feet per second) for gypsum and anhydrite of the Tamarisk Member of

TABLE 5.—*Measured velocities and calculated elastic moduli for rock salt near the position of the Gnome explosion*

[From Dickey (1964, p. b109). All arrival times determined from comparison of two or more records from each line of measurement except those for line *J-O*. Only one acceptable record was obtained from line *J-O*. Line *Y-Z*, the preexplosion line of measurement, is 5.5 feet higher stratigraphically than the other lines. Measurements by D. D. Dickey and D. R. Cunningham]

Line of measurement (fig. 9)	Distance from explosion point (ft)	Length of line (ft)	Traveltime of first arrival (milliseconds)		Velocity (fps)		Poisson's ratio	Young's modulus (10^6 psi)	Shear modulus (10^6 psi)	Bulk modulus (10^6 psi)
			Compressional	Shear	Compressional	Shear				
Postshot measurements										
A-C.....	80-110	34.99	2.9	6.05	12,100	5,800	0.35	2.6	0.95	2.9
B-C.....	80-110	32.15	2.7	5.6	11,900	5,750	.35	2.5	.93	2.8
G-E.....	140-205	66.80	5.6	10.4	11,900	6,400	.30	3.0	1.1	2.5
G-F.....	140-205	67.09	5.7	10.4	11,800	6,450	.29	3.0	1.2	2.4
J-O.....	235-350	114.74	8.8	14.9	13,000	7,700	.23	4.1	1.7	2.6
J-K....	235-325	90.52	7.0	13.1	12,900	6,900	.30	3.5	1.4	2.9
U-W....	600-785	186.22	13.4	24.4	13,900	7,650	.29	4.2	1.6	3.3
Preshot measurements										
Y-Z.....	5-85	81.37	6.05	11.5	13,500	7,100	.31	3.5	1.4	3.1

the Rustler Formation to 5,072 fps for sandstone of the Gatuna Formation. Transverse velocities range from 9,487 fps for the same gypsum and anhydrite sample to 3,244 fps for the Magenta Member of the Rustler.

CHANGES IN PHYSICAL PROPERTIES

The dynamic properties of the rock salt in the underground workings at Project Gnome were calculated from preshot and postshot in situ measurements of the compressional and shear velocities of acoustic waves. This work was described by Dickey (1964). Figure 9 shows the plan of the preshot and postshot workings and location of the sonic-velocity stations. Velocities and calculated elastic moduli are shown in table 5.

Dickey (1964, p. B111) concluded that:

> * * * the results of this study showed that (1) although fracturing of this rock is detectable by the acoustic method used, compaction is not, and (2) the elastic moduli are changed for reasons other than compaction. Furthermore, the amount of fracturing is semiquantitatively estimable by acoustic means. Compaction is not shown by the changes in elastic moduli caused by the explosion, because of the larger changes in elastic moduli not related to compaction. These changes, however, may indicate the amount and position of changes in stress of the rock surrounding an explosion.

Density changes were not detected in laboratory measurements (table 6), and, therefore, compaction was less than 1 percent on any sample tested.

Table 6.—*Physical properties of samples of halite from unit 10, Salado Formation*

[Analysts: John Moreland, Jr., and E. F. Monk. Salt-saturated kerosene density: 0.8098 at 19.5°C]

Lab. No. P2-	Location in drift	Rock type	Effective porosity (percent)	Grain density	Dry-bulk density, mercury displacement	Saturated-bulk density (in salt-saturated kerosene)	Total porosity (percent)
1198	Sta. 6+94.	Preshot halite.	1.0	2.17	2.14	2.15	1.2
1012	105 ft from shot-point.	Postshot halite.	1.02	2.18	2.11	....	3.65
1199	....do....	....do....	.9	2.18	2.14	2.15	1.7
1200	....do....	Postshot vein halite.	.9	2.17	2.13	2.13	1.9

MINOR ELEMENTS IN SALADO FORMATION IN THE GNOME DRIFT

The Gnome drift, whose rocks show a sequence of cyclic deposition, provided a rare opportunity to study the distribution and association of minor elements of evaporite rocks in a nonmineralized part of the Salado Formation.

Semiquantitative spectrograph analyses were made on samples from seven stratigraphic units exposed in the Gnome drift and from four replacement zones in these units. In addition, analyses for minor elements were made for comparative purposes on samples of the langbeinite and sylvite ore zones from the 800- and 900-foot levels of the International Minerals and Chemical Corp. mine, 12 miles northwest of the Gnome site, and on samples of selenite crystals precipitated in Salt Lake, 8 miles west of the site. These analyses were by Gard, Cooper, and others (1962, tables 9, 11). Samples from the Gnome drift are described in table 7 of the present report, and the semiquantitative spectrographic analyses of these samples are summarized in table 8.

Many elements either compose the clay minerals or are closely associated with the clays. These elements are, in order of decreasing abundance: potassium, magnesium, calcium, silica, aluminum, iron, titanium, lithium, boron, barium, manganese, vanadium, zirconium, chromium, molybdenum, copper, nickel, yttrium, gallium, cobalt, scandium and ytterbium. Several elements that are associated with the clays also form parts of one

Table 7.—*Description and stratigraphic position of samples of Salado Formation analyzed by semiquantitative spectrographic methods*

[All samples from Gnome drift]

Sample	Stratigraphic unit within Salado Formation	Description
30	10 (upper part).	Halite rock, colorless.
31	....do......	Halite rock, orange, translucent; contains trace of disseminated orange polyhalite.
33	....do.......	Halite rock; composite sample.
34	10 (lower part).	Halite rock; contains some polyhalite.
35	....do........	Halite rock; contains some gray clay and trace of polyhalite.
37	11............	Halite rock; contains gray clay and streaks of polyhalite.
39	12............	Halite rock; contains gray and brown clay.
41	13 (upper part).	Halite rock, orange; shows streaks of orange polyhalite and brown clay; contains trace of gray clay.
42	....do........	Halite rock, colorless; contains some brown clay and trace of orange polyhalite.
43	13 (lower part).	Halite rock; contains some brown clay and polyhalite.
46	14............	Halite rock; contains blebs of orange polyhalite.
47	15 (upper part).	Polyhalite rock, moderate-reddish-brown; contains trace of halite.
48	15 (middle part).	Polyhalite rock, moderate-reddish-brown; contains trace of halite.
49	15 (lower part).	Same; contains inclusions of gray clay.
50	15............	Underclay, gray; contains some halite and trace of polyhalite.
51	16............	Halite rock; 0.3- to 0.5-in.-square crystals; contains some gray clay and orange polyhalite.
52	16............	Halite rock; 0.3- to 1.0-in.-square crystals; contains some brown clay.
53	16............	Halite rock, colorless; contains some blebs of orange polyhalite.

TABLE 8.—*Summary of semiquantitative spectrographic analyses of evaporite rocks (Salado Formation) from Gnome drift, in percent*

[Samples described in table 7. Analyst: J. C. Hamilton. M, major constituent (greater than 10 percent); L, looked for but not detected. Average: where results are reported as 0 or <, with a number, the half-value of the threshhold of detection was used in determining the average. Other elements looked for but not detected: phosphorus, silver, arsenic, gold, beryllium, bismuth, cadmium, germanium, hafnium, mercury, indium, lanthanum, nickel, palladium, platinum, rhenium, antimony, tin, tantalum, tellurium, thorium, thallium, uranium, tungsten, zinc, and cerium]

Unit in Salado Formation	10	11	12	13	14	15		16
Sample Nos.	30, 31, 33–35	37	39	41–43	46	47–49	50	51–53
Si	0.007 -0.15	0.3	1.5	0.3 -0.7	0.007	0.03 -0.3	M	0.003 -0.3
Al	.015 - .15	.3	.7	.3	.007	.015 - .3	1.5	<.005 - .15
Fe	.007 - .03	.05	.3	.1 - .2	.002	.07 - .3	.7	0 - .03
Mg	.15 -2	.7	3	.7 -2	.5	5	7	.15 - .5
Ca	.07 -7	.5	.07	.07 -5	1.5	M	.7	.1 - .5
Na	M	M	M	M	M	1	7	M
K	0-5	1	1.5	0-5	2	M	7	0-1
Ti	.0007- .003	.005	.03	.01 - .015	<.0005	.0015- .015	.15	<.0005- .007
Mn	0- .0003	.0007	.005	.001 - .0015	L	.0005- .003	.015	0- .0007
B	L	L	.005	L	L	L	.05	L
Ba	<.0002- .0015	.007	.005	.0005- .003	<.0002	.005 - .007	.015	<.0002- .0005
Co	L	L	L	L	L	L	.0007	L
Cr	0- .0002	.0005	.002	.0003- .0005	L	0- .005	.005	L
Cu	.0001- .001	.0001	.0002	.0002- .0003	.00015	.0002- .0015	.002	0- .0007
Ga	L	L	L	L	L	L	.0015	L
Li	L	L	.03	L	L	L	.1	L
Mo	L	L	L	L	L	L	.003	L
Ni	L	L	L	L	L	L	.002	L
Sc	L	L	L	L	L	L	.0007	L
Sr	.003 - .3	.05	.005	.005 - .3	.07	.15 - .3	.015	.005 - .05
V	L	L	.002	0- .001	L	.001 - .0015	.007	L
Y	L	L	L	L	L	L	.002	L
Yb	L	L	L	L	L	L	.00015	L
Zr	L	L	.0015	L	L	L	.007	L

or more minerals. Potassium and magnesium form an integral part of the polyhalite lattice, and calcium is also a major constituent of polyhalite. Included iron, which is also concentrated in the clays, imparts the characteristic reddish-orange color to polyhalite. Barium is more abundant in the clay concentrates and in the sulfate mineral polyhalite than in the halite.

Boron is commonly associated with the clays but was not found in the halite or polyhalite. Strontium is relatively abundant in polyhalite but is less abundant in halite rocks containing accessory polyhalite as blebs, streaks, or disseminated particles.

Elements reported by Moore (1958b, tables 4, 5) in anhydrite, polyhalite, and halite rocks of the Salado Formation, but not determined by the semiquantitative spectrographic method, are: chlorine, sulfur, oxygen, hydrogen, bromine, carbon, fluorine, iodine, and selenium. Thorium and zinc were also reported by Moore but are not present in the Gnome samples in amounts detectable by this method. Six elements not previously reported were detected by the spectrographic method: chromium, lithium, scandium, yttrium, ytterbium, and gallium.

MINERALOGY AND PETROGRAPHY OF THE SALADO FORMATION NEAR THE DEVICE CHAMBER

A petrographic study was made by B. M. Madsen of the evaporite rocks near the device chamber, and the insoluble clastic material from these rocks was studied by Julius Schlocker. Seventeen thin sections from a 100-foot section of the recovery-hole core and four thin sections from rock samples collected in the drift were studied and described. The 100-foot section of the core extended from 50 feet above to 50 feet below the device chamber. The predominant mineral is halite, and lesser amounts of polyhalite and clay are present. The other minerals present are magnesite, quartz, chlorite, mica, and anhydrite, which generally occur in amounts of 1 percent or less.

HALITE

Halite makes up more than 90 percent of the 100-foot section of the recovery-hole core. The halite rock is hypidiomorphic-granular and shows no strain birefringence or schistosity in thin section. The grains range in size from 0.75 to 50.8 mm, but most are between 7.62 and 17.8 mm. A plot of the crystal size of the halite on a strip log showing lithology and depth shows a slight tendency for the size of the halite crystals to decrease as the disseminated-clay content increases. More than half the halite crystals contain negative crystals (crystal-shaped voids) filled with a liquid and gas. These negative crystals are both cubic and rectangular, but they always maintain right-angle corners, and they are as much as 0.05 mm in diameter. Generally the negative crystals occur in zones three or four crystals wide and parallel to the cleavage of the host halite crystal, but in some the zones of negative crystals are at a 45° angle to the cleavage. The negative crystals also occur as curving zones or in small irregular masses of several hundred crystals.

POLYHALITE

The second most abundant mineral in the 100-foot section of core is polyhalite, which ranges in color from white and gray to brick red. In thin section the polyhalite exhibits a variety of textures, which are divided into four types (Schaller and Henderson, 1932, p. 51). These types may occur singly, intimately mixed, or grading from one to the other.

The first texture is fine grained, the crystal size ranging from 0.001 to 0.02 mm, and is allotriomorphic-granular. The fine-grained texture generally characterizes the more massive forms of polyhalite.

The second texture is coarse grained, the crystal size ranging from 0.02 to 0.5 mm. Crystals range from anhedral to euhedral, but are mainly subhedral and twinned.

The third texture is euhedral twinned and includes two distinct forms, both of which show laminar and sector twinning, are colorless, and range in crystal size from 0.2 to 6.0 mm. One form of the euhedral-twinned group is spear shaped (fig. 7*A*), and the length is no greater than twice the width. The second form of the euhedral-twinned variety is the lath (fig. 7*B*). The length of the euhedral-lath twins is generally at least 10 times the width; normally this form occurs as inclusions in halite crystals or as projections into a halite crystal. The lathlike crystals range in width from 0.01 to 0.5 mm and in length from 0.2 to 5.0 mm.

The fourth texture is fibrous and is characterized by crystals that range in width from 0.001 to 0.004 mm and in length from 0.1 to 0.9 mm. The fibrous and fine-grained granular textures are gradational and commonly occur together. Individual fibrous crystals are common in the halite. The fibrous form shows all gradations from almost perfect spherulites to faint wisps of fibers.

Color.—Polyhalite imparts a light-orange or reddish-brown color to the rock and is the most conspicuous megascopic mineral. The color depends on the amount of included hematite in the polyhalite. Hematite occurs as an extremely fine dust disseminated through the fine-grained and fibrous forms of polyhalite but is absent in the euhedral forms, which are colorless. Hematite also occurs in the brown clay and along some cleavage planes in the halite immediately adjacent to the brown clay inclusions. Mottling observed at the top of the Union anhydrite, a locally used name, in the Salado Formation is due to a mixture of hematitic fine-grained to fibrous polyhalite and colorless coarse-grained polyhalite.

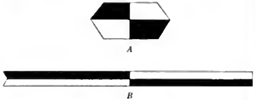


FIGURE 7.—Twinned polyhalite crystal forms: *A*, spear shaped; *B*, lath shaped.

Structure.—Polyhalite occurs as blebs, growths, streaks, seams, beds, bands, and disseminated crystals or particles. The terms "bed," "band," and "seam" are applied to horizontal laminae of polyhalite which may be brick red, orange, or white and range in thickness in this part of the section from a few hundredths of a foot to 1.5 feet. In texture these laminae are mostly fine grained or fine grained to fibrous. At the contact of a polyhalite band with halite, long euhedral-twinned laths of polyhalite usually project into the halite. Rounded masses of coarse-grained polyhalite and remnants of large euhedral-twinned crystals of polyhalite are also present in some bands.

Polyhalite is nearly ubiquitous in the halite as small masses that make up 1–10 percent of the rock. Where these masses are roughly equidimensional, they are called blebs or growths; if they are at least three times longer than they are wide, they are called streaks. These small masses average 1–5 mm in width, are orange, and occur in or between halite crystals. Generally they have a center of fine-grained polyhalite, and long fibrous or euhedral laths make up an outer rim that projects into the surrounding halite. The laths projecting into the halite are so evenly developed that they look like the teeth of a comb or the spokes of a wheel. The centers of some blebs are mixtures of coarse- and fine-grained polyhalite or of fine-grained and fibrous polyhalite. A few blebs are composed of a mat of fibrous crystals and contain no fine-grained polyhalite.

ANHYDRITE

Anhydrite was found in only two thin sections, where it amounted to 1 percent or less. One thin section is from a sample taken 1.5 feet below marker bed 121 and shows anhydrite crystals at least 5.5 mm long that have been badly corroded by halite. The other section is from a sample taken from the top of marker bed 120 and shows a single perfectly euhedral anhydrite crystal in halite. This crystal is 0.21 mm long and 0.07 mm wide.

CLASTIC MATERIAL

The presence of clastic material in the Salado Formation is an anomaly. This material was probably not brought in from the open sea to the south, and a postulated landmass to the northwest must have been many miles away. The clastic material is mainly clay and silt size (table 9), has minor amounts of sand-sized material, and could have been carried in suspension by streams from such a landmass; possibly some of this material was airborne. According to Julius Schlocker (written commun., 1961), the sand-sized material consists of doubly terminated quartz crystals that attain a maximum diameter of 0.6 mm. Cores of some of these euhedral crystals show ghosts of well-rounded quartz grains, which indicate that the crystals were much smaller when deposited and that they acquired overgrowths of quartz after deposition. Clasts of other minerals, which are sparse and mostly very fine grained, include microcline, plagioclase (mostly oligoclase), and quartz with biotite inclusions.

TABLE 9.—*Approximate size and heavy-mineral composition of clastic material in units 11–13 of the Salado Formation in Gnome drift*

[Julius Schlocker, written commun., 1961]

Unit	Percentage of material of given size			Heavy minerals (percent)
	Less than 2 microns	Silt	Sand	
11	75.0	15.0	10.0	0.17
12	78.3	14.5	7.2	.22
13	73.2	19.3	7.5	.13

The heavy-mineral assemblage, according to Schlocker (written commun., 1961), is approximately the same in all units and is as follows.

Abundant: ilmenite; leucoxene; magnetite with drusy surfaces; biotite, green and brown; muscovite.

Common: hornblende, blue-green to yellow-green, pale-brown to brown, green to brown; monazite; epidote; chlorite; tourmaline, yellowish-red-brown to colorless, greenish-brown to colorless, dark-green to pale-brown.

Scarce: zircon; rutile; apatite; sphene; clinozoisite; garnet, pale-brown, colorless, and rutilated; iron sulfides.

Rare: oxyhornblende; anatase; anhydrite; actinolite-tremolite; sillimanite in quartz; hypersthene, etched.

Clay.—The term "clay" is here used for the water-insoluble minerals of clay and silt size. Clay-sized particles make up more than 75 percent of this material. This clay-silt mixture occurs as irregular streaks, inclusions, and partings in the Salado Formation. The partings vary in thickness from a featheredge to 19 mm. The silt-sized material was examined with the petrographic microscope, and the clay-sized fraction was analyzed by X-ray diffraction by Julius Schlocker of the Geological Survey.

The silt-sized material is made up largely of quartz, magnesite, chlorite, and mica. All clay-sized samples that were examined are of similar composition, according to Schlocker (written commun., 1962), and contain about equal proportions of (1) interstratified chlorite and montmorillonite having both regular 1:1 alternations and random alternations; (2) mica, both trioctahedral (biotite: phlogopite type) and dioctahedral (muscovite type); and (3) chlorite. A trace of magnesite is present in the clay-sized material. In the halite rock the proportion of clay- and silt-sized grains ranges from 0 to 40 percent, but averages 1–3 percent. Talc, which commonly occurs in halite rock, was not found. The color of the clay ranges from gray to gray green to reddish brown. The reason for the color difference was not determined. The colors persist even in the less than 2-micron-sized fraction and in the clay minerals themselves.

EFFECTS OF THE NUCLEAR EXPLOSION

The Gnome shot was fired at noon on December 10, 1961, and produced a yield of about 3 kilotons (equivalent to 3,000 tons TNT). At shot time the ground surface above the detonation point rose about 5 feet and then dropped (Hoy and Foose, 1962). Shortly thereafter, observers 5 miles away felt a strong ground roll.

The ground surface was permanently domed upward for more than 400 feet radially around ground zero, the maximum rise being 1.9 feet. An irregular pattern of radial and concentric fractures with slight displacement was formed in the stabilized caliche pad and adjacent dune sand. Most of the concentric fractures had the outer side upthrown (Hoy and Foose, 1962).

One interesting surface effect was the appearance shortly after the shot of a large number of freshly dug or recently cleaned-out animal burrows in the vicinity of ground zero (Hoy and Foose, 1962).

The explosion melted approximately 3.2×10^6 kilograms of salt and produced a standing cavity with a volume of about 27,200 cubic meters (Rawson and others, 1965). The shock of the explosion opened radial fractures and produced some thrust faults in the adjacent rock that were filled with melted salt and rock fragments. Fractures as much as 130 feet from the cavity were injected with radioactive gases, as shown by blue coloration of the salt.

A few moments after firing, the shot vented into the drift and up the shaft, having breached the salt in the vicinity of the line-of-sight neutron-tube hole and having blown a rupture disk out of a ventilation hole in the blast door. Stemming at the bypass section near the blast door prevented any ultrahigh-pressure gases or particles from escaping through the vent. For more than a day clouds of steam laden with short-lived radioactive gases drifted gently from the shaft and ventilation pipes. Air and surface contamination were closely monitored, and traffic near the site was stopped for a short time to ensure public safety. Because of the radiation, reentry to the main station was delayed for nearly a week.

The shot was completely contained by the rocks directly over the shot, and there has been no indication that any radioactivity leaked into the ground water in the Culebra Dolomite Member of the Rustler Formation.

EFFECT ON THE SHAFT

Damage to the shaft was very limited. At 75 feet and 90 feet below the collar, the reinforced-concrete shaft lining displayed horizontal fractures, with minor lateral movement, around its entire circumference. The concrete liner above each fracture had moved radially away from ground zero relative to the part below. Neither fracture had a displacement of more than one-fourth inch. The differential movement at these two positions was probably localized by two contacts: at 90 feet by the contact of the Dewey Lake Redbeds with the less consolidated overlying Gatuna Formation, and at 75 feet by a contact between conglomerate and less consolidated sandstone in the Gatuna.

The concrete lining contained several minor horizontal fractures, with showed no visible displacement, at depths of 160 and 480 feet. The lower of these, about 15 feet above the top of the water-bearing Culebra Dolomite Member, produced a slight water seep. However, no large amount of water seeped from the Culebra into the shaft or the cavity (J. B. Cooper, U.S. Geol. Survey, oral commun., 1962). Below the concrete lining there was small-scale spalling of salt and clayey beds from the shaft wall.

EFFECT AT THE MAIN STATION

At the main station (junction of the shaft and drift) damage from the shot consisted of large-scale spalling from the ribs, especially at exterior corners, and of slabbing from the back of about 3–4 feet of units 13 and 14, which parted at the contact with the clayey units 11 and 12. Where roof bolts, netting, and a monorail were affixed in the back, large slabs of units 13 and 14 were hanging free, and this loose rock had to be removed during cleanup operations.

The marker bed 121 polyhalite (unit 15) was bleached to a depth of a few millimeters, probably by the steam that leaked from the cavity. The 16-foot-deep sump at the bottom of the shaft was filled with water condensed from the steam, and, for a few weeks after the explosion, ankle-deep water was present on the sill (floor) at the main station.

THE REENTRY DRIFT

Because radiation levels were high in the original drift, a reentry drift was driven parallel to and about 30 feet south of the original drift. The reentry drift was constructed to allow close-in sample-recovery drilling and recovery of instruments buried before the shot.

The reentry drift and appurtenant exploratory laterals were mapped in June 1962, 6 months after the shot was fired (pl. 2). Unlike the original drift, which was horizontal, the reentry drift was sloped slightly downward, following the bedding, to take advantage of the parting between beds 11 and 12. This provided a smooth strong back which did not require any bolting. The reentry drift, thus, exposed the same beds for its entire length.

Seeps.—Explosion effects, such as faults, fractures, and irradiated salt, were not seen in the reentry drift beyond 250 feet from the shotpoint. The most obvious difference observed between the salt exposed in the reentry drift and that exposed in the preshot drift was the presence of water seeps along the reentry drift. Several seeps were visible at the base of unit 15 (from the clay underlying the polyhalite) and from the thin clayey units 11 and 12. This water must have been derived from the steam created by the blast. If it had merely been moisture squeezed out of the clays by the blast, it would have been more widely distributed and should have been more abundant where the clays were thicker. Seeps also were associated with the grout-filled instrument holes intercepted by the drift. Some of this water could have been introduced by the grouting operation.

VENTING

Venting occurred because the larger-than-anticipated cavity and spalling from the cavity walls resulting from the explosion reduced the separation between the cavity and the end of the straight part of the drift. Radial fracturing from the cavity provided avenues of escape for the high-pressure steam, and, once open, these fractures became enlarged by solution and erosion. Salt along the path of the steam was dissolved and sculptured in potholelike cusps (fig. 8). At the drift elevation, the thin, potentially weaker, clayey halite beds—units 11 and 12—probably contributed by providing a lubricated zone of weakness.

THE CAVITY

An open cavity about 70 feet high and more than 150 feet across resulted from the detonation and postshot collapse (fig. 5). In plan, the cavity is roughly oval and is elongated in the same direction as the drift (fig. 9). Postshot drilling indicated that strata 200 feet above the shotpoint were permanently displaced 5 feet

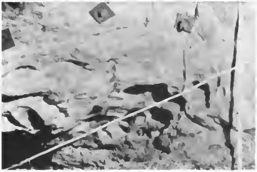


FIGURE 8.—Steam-eroded potholes in unit 10 where shot vented into preshot drift. Corner of preshot drift shows at lower left.

upward (Lawrence Radiation Lab., written commun., 1962), and that the Union anhydrite, a locally used name, in the Salado Formation, which lay 55 feet below the shotpoint, was displaced downward more than 10 feet (T. S. Sterrett, U.S. Geol. Survey, oral commun., 1962).

The bottom of the cavity contains a heap of rubble composed of large angular blocks of salt which have fallen from the vault and sides (frontispiece). Bowed-up ends of strata crop out in the walls of the cavity, and the walls exhibit no evidence of melting. Colors in the cavity are spectacular and include red, brown, white, orange, yellow, and blue. The yellow and blue colors are caused by radiation damage to the salt. Radial fractures are seen in the vault of the cavity; these fractures narrow radially from the center of the vault. They are filled with white salt evidently redeposited from solution, and thin white salt stalactites hang from the vault and sides (frontispiece).

EXPLOSION-INDUCED STRUCTURE

Detailed geologic mapping of the reentry drift disclosed that the detonation had surprisingly little effect on the strata lying at the same altitude as the shotpoint. Evidence for this is, of course, confined to what could be seen in the limited postshot mine workings. Undoubtedly, blast effects will be found in salt beds above and below the drift level if exploration is carried out at other levels. A belt of salt about 30 feet high in the cavity wall at about device level seems to have been moved radially outward as a unit, and the beds above it are bent upward. The contact between beds showing these different types of movement lies about at marker bed 119 (detailed measured section, p. 24), and it is postulated, therefore, that structures similar to those exposed in the postshot workings will be found at least to that level. Beds logged in the recovery hole and shaft can be identified clearly in the cavity walls.

Major lateral blast-induced effects were largely confined to a radial distance of about 140 feet from the shotpoint, although curving vertical faults, concave toward the preshot drift and showing slight horizontal movement, are found as far as 250 feet away from the

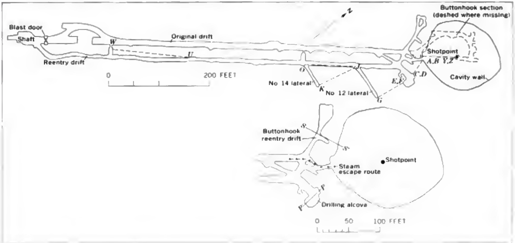


FIGURE 9.—Map of underground workings and cavity. Sonic velocity stations are indicated by italic letters, and lines of sonic measurement, by dashed lines; from Dickey (1964). Enlargement shows location of geologic cross sections (figs. 11, 12). Arrows show route of venting.

shotpoint. These faults probably were formed because of the relief effect of the preshot drift, although they may be tear faults representing the ends of thrust faults that lie concealed above the mine workings.

The contact between the thin clayey halite beds that form units 11 and 12 forms the back of the reentry drift. In many places the bottom of unit 11 displays the cast of ripple marks that were present on the upper surface of unit 12. These ripple marks were destroyed by differential movement along this contact and are commonly replaced by slickensides to about 230 feet from the shotpoint. Beyond there the ripple marks are intact. In most places the slickensides trend N. 35° E., roughly radically from the shotpoint; but at station 8+58, near the junction of the reentry drift and the lateral IH-8, a set of slickensides trends N. 80° E., indicating that some motion was not radial.

STRUCTURE IN CONFINED SALT

Except for the radial fractures seen in the vault of the cavity and a few others exposed in the buttonhook reentry drift, blast-produced faults in the confined salt appear to be restricted to a 10-foot section of salt (units 13–15) bounded above by the clayey layers (units 11 and 12) and below by the clay at the base of the polyhalite. These fractures are mainly thrust faults that dip both toward and away from the cavity and die out in the clay layers. Overthrusts are more common than underthrusts. The thrust faults end laterally by curving downward into vertical tear faults that die out in the salt beds.

Typical examples of these faults are seen in the drilling alcove (section *A–A′*, pl. 2) where two thrust faults that dip toward the cavity are well exposed. The one exposed in the east wall has 2 feet of throw, which can be measured from the offset of the contact between units 13 and 14 in the alcove wall. A 2-foot-square hole dug in the wall revealed that, although unit 15 is offset, the fault dies out in the underclay and does not offset unit 16. The north end of this fault dies out in a tear fault in unit 13. The other fault has only one-half foot of throw and can be traced in the south, west, and north walls of the alcove. The lower end of the fault originates in the clay under unit 15 and offsets the polyhalite slightly, but the upper end is not exposed (fig. 11*A*). Figure 10 is an interpretation of these two faults.

In the No. 12 lateral, which was driven to recover an instrument, unit 14 displays horizontal hairline fractures along the wall nearest the cavity that are similar in appearance to the fault just described. The offset on these fractures could not be determined, nor is the direction of dip known, but any movement along them must have been very slight. The gouge in these fractures is blue in places, indicating that radiation leaked this far along the fractures. There is no indication in this lateral of any offset of the polyhalite bed.

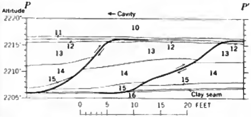


FIGURE 10.—Geologic cross section *P–P′* of drilling alcove, showing thrust faults. Right fault shown in figure 11*A*. See table 2 for description of numbered stratigraphic units.

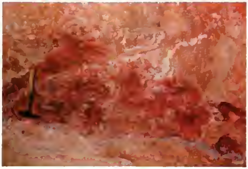
Adjacent to the cavity, faulting is more common and more complex, although no faults were seen that had more than a few feet of displacement. On many faults at least some component of movement could be measured, from offset either of beds or of mudcracks in unit 13.

According to a resurvey of grout-filled instrument holes, total lateral displacement 100 feet from the shotpoint was 16 feet. An instrument 127 feet from the shotpoint had been moved away 8 feet. Bags of salt in the alcove at the end of the straight section of the preshot drift that initially were about 90 feet from the shotpoint were about 120 feet away and had been lithified into well-compacted salt breccia (fig. 11*B*). Outlines of individual bags with cloth fragments between are still discernible.

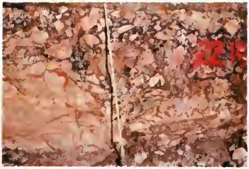
STRUCTURE IN UNCONFINED SALT

On the west side of the shotpoint, the buttonhook drift remained open up to shot time. It was designed to be blown shut when the shot went off, and in this it was eminently successful—material that had been left in the open drift was blown 35 feet from its original position and sealed tightly in a well-lithified intrusive breccia of salt. Complex thrust faulting accompanied by intrusive breccia is found as far as 110 feet from the shotpoint on this side of the cavity.

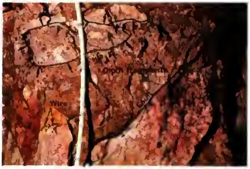
Faulting.—The rocks observed in the buttonhook reentry drift were complexly faulted. Several thrust faults can be seen along the right rib, and many of them contain melt. The section exposed in the left rib is unfaulted, but the beds lie about 4 feet above their preshot altitude. The thrust faults generally die out laterally in downcurving tear faults. The main rock unit involved in the faulting is unit 10, which has been thrust under itself. A small lateral driven toward the cavity revealed details of one of these faults (figs. 11*C*, 12).



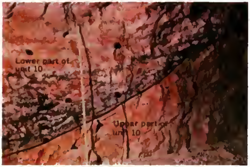
A



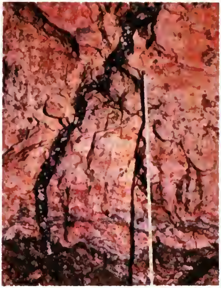
D



B



C



E

FIGURE 11.—Thrust faults, lithification, and brecciation resulting from the Gnome explosion. *A*, Thrust fault offsetting unit 15 (polyhalite) in drilling alcove. Fault originates in thin clay at base of polyhalite (left of hammer) and does not offset unit 16 (below hammer). *B*, Lithified salt bags. Note outline of bag shape top center indicated by arrows and cloth fragments near "2" on rule. (See pl. 2, section *B–B'*, left rib.) *C*, Underthrust fault in unit 10 in buttonhook reentry drift. Fault parallels bedding of lower plate, following a thin clay seam that normally lies 5.5 feet above basal clayey halite at left. Cavity to right. Scale is 3 feet long. (See pl. 2, section *E–E'*, left rib.) *D*, Intrusive breccia in buttonhook recovery drift. Blocks are composed of intensely granulated halite crystals, mainly from unit 10. Black matrix is chilled salt melt containing disseminated opaque black carbon and the blast-produced minerals laurionite and galena. (See pl. 2, section *D–D'*.) *E*, Intrusive breccia vein in rib of buttonhook recovery drift. Rule is 30 inches long. (See pl. 2, section *D–D'*.)

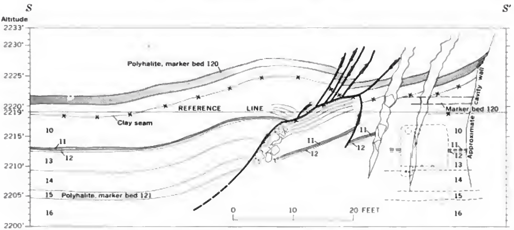


FIGURE 12.—Geologic cross section *S–S′* through buttonhook reentry drift. See table 2 for description of numbered stratigraphic units. Dashed lines indicate original position of buttonhook drift and strata.

The determination of the details of the structure from the limited exposures available was facilitated by the presence of several thin distinctive beds in unit 10.

Intrusive breccia.—Intrusive breccia is associated with the faulting along the right rib of the buttonhook reentry drift. The breccia consists of fragments that are largely composed of salt from unit 10 and range in diameter from a few millimeters to several tens of feet. These brecciated salt fragments occur in a matrix of black salt melt (fig. 11*D*). The black color is imparted by two blast-produced lead minerals—laurionite and galena—and disseminated carbon. The breccia contains twisted fragments of mine rail, steel ventilation pipe, wire, aluminum conduit, and cable covering and a few slightly scorched fragments of wood that had been left in the buttonhook drift. These fragments now lie about 35 feet from their original position. Salt in the blocks was granulated by the shock but not melted. Halite crystals in unit 10 ranged from 10 to 20 mm in diameter before the shot (fig. 13) but were shattered by the explosion and reduced to angular fragments measuring a millimeter or less (fig. 14*A*). This granulation must have resulted from the amount of free movement in these blocks, because it is not seen elsewhere, even in the cavity walls. Halite crystals in the cavity walls are fractured, but their outlines are plainly visible. Bedding planes in the larger fault blocks are distinct and still roughly horizontal, although the smaller blocks in the breccia are randomly oriented. Bedding planes are not disrupted within the larger blocks, although they may display drag against faults.

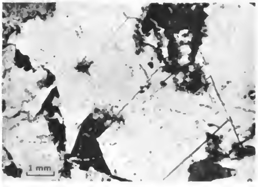
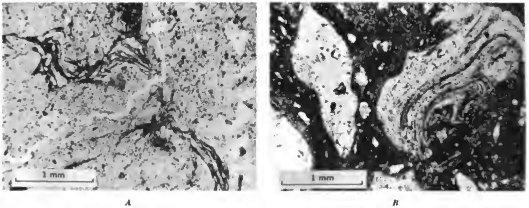


FIGURE 13.—Photomicrograph of preshot salt. Dark areas are polyhalite and clay. Note cleavage planes.

The density and porosity of samples of the granulated halite from the breccia and some of the vein material were determined in the laboratory (table 6) and compared with the results obtained on preshot sample (tables 3, 4). If any change in the density occurred, it was less than the limit of error due to sampling a slightly variable unit. Total porosity appears to have increased slightly, probably owing to the increased number of grain boundaries.

NEW MINERALS FORMED

Associated with the blocks of granulated salt are black veins of intrusive breccia containing the manmade



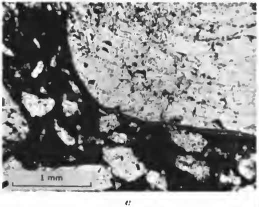


Figure 14.—Photomicrographs of intrusive breccia resulting from Gnome explosion. *A*, Swirl pattern of fragments in intrusive breccia veinlet; black areas are carbon, laurionite, and galena. *B*, Plastically deformed salt fragment in intrusive breccia. *C*, Chilled border of melt against fragment; chilled border contains fewer opaque minerals.

minerals laurionite[1] and galena (Gard, 1963). These veins are not radioactive. The veins, which are seldom more than a few inches wide and are generally radial to the shotpoint (figs. 11*E*, 15), display sharp contacts with the host rock and are intruded along faults and fractures. The black veins and breccia matrix consist of melted and recrystallized salt and contain minute opaque black minerals disseminated between the salt crystals and sharp-bordered fragments of clear unmelted plastically deformed salt. Some of the unmelted salt fragments have a very thin selvage suggesting partial melting, and many of the fragments show warping and bending of bedding and cleavage suggesting plastic deformation (fig. 14*B*). In one thin section a tiny vein displays flow textures with warping and swirling of fragments reminiscent of that commonly seen in welded tuffs (fig. 14*A*). Minute fragments of copper and steel wire are not uncommon constituents.

Thin sections of the veins show that the melt has narrow chilled borders where it is in contact with many of the larger fragments and wallrock. The chilled borders are relatively free of lead minerals, but those minerals occur in the interior of the veins in the form of dust lying between the tiny crystals of melted salt (fig. 14*C*).

A mixed grab sample of black salt that was thought to be representative of the melt was collected from several places along the buttonhook recovery drift and submitted to the laboratory for analyses. Theodore Botinelly (written commun., 1962) reported as follows:

> A part of the sample was leached with distilled water in the ultrasonic agitator. The X-ray diffractometer pattern of the black (dark blue-gray) residue showed laurionite (Pb(OH) Cl), galena (PbS), and a mica. One fragment of vein material was cleaned of salt and leached with water. The residue amounted to approximately 15 percent of the weight of the original material. Slight effervescence with acid indicates some carbonate is present. (Magnesite is present in the preshot clays.) Microscopic examination showed, in addition, doubly terminated quartz crystals with a small 2V. Quartz from a preshot sample of fairly pure salt showed no 2V. Also present in the residue from the preshot salt were flakes of muscovite.
>
> Synthetic laurionite was prepared from lead acetate and sodium chloride solutions. Dehydrated at 150°C. for 12 hours it broke down to a mixture of lead oxides and lead chlorides. The mixture did not revert to laurionite in 48 hours. After 64 hours

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[1] Laurionite was first found at Laurium, Greece, where it is formed by the action of sea water on slags from lead mines that were operated during the time of Pericles (4th century B.C.).

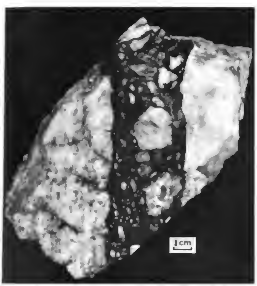

FIGURE 15.—Hand specimen showing vein of intrusive breccia. Unmelted salt fragments set in matrix of black melted salt. Black color is caused by presence of carbon and of lead minerals laurionite and galena, which were formed by heat and pressure of the shot.

in an atmosphere saturated with water, the mixture showed a laurionite X-ray pattern.

Induction-furnace determinations, by I. C. Frost, showed total carbon content of the insoluble residue of two samples to be 5.64 and 6.74 percent.

ELEMENTS INTRODUCED

Comparison of the semiquantitative spectrographic analysis of the insoluble residue from the black veins (table 10) with analyses of the rock units exposed in the preshot drift (table 8) shows that silver, bismuth, lead, tin, zinc, and carbon are new elements that must have been introduced by the explosion. There are two potential sources for these elements: first, the nuclear device and material placed around the device, and, second, material left in the buttonhook drift after excavation.

At the time of the explosion, large quantities of lead, iron, and paraffin were present in the shielding block used in the device-performance measurements. Substantial amounts of wood and aluminum also were present.

The postshot presence of silver, bismuth, and zinc, which were not detected in preshot samples, is readily accounted for, as they are common minor impurities in lead from western smelters. The additional copper could have come either from the vicinity of the device or from a wire fragment left in the buttonhook drift that was unnoticed in the sample. The presence of zinc is harder to explain, but both the zinc and the copper could have been derived from brass fittings around the device. Carbon could have come from vaporized paraffin or wood near the device.

TABLE 10.—*Semiquantitative spectrographic analysis of insoluble residue of vein material resulting from the Gnome explosion*

[Asterisk indicates slight increase or decrease from amount present in preshot samples (table 8), probably due to analytical error. M, major constituent (greater than 10 percent)]

Element	Percent	Element	Percent
Si	M	Cr	0.005
Al	1.5	Cu	.7
Fe	1.5	Ga	.0015
Mg	M	Li	*0
Ca	.5	Mo	*0
Na	*1.5	Ni	.007
K	*1.0	Pb	M
Ti	.15	Sc	.0005
Mn	.015	Sn	.007
Ag	.003	Sr	.01
B	.05	V	*.005
Ba	.01	Y	.002
Bi	.005	Yb	*.0002
Ce	0	Zn	.07
Co	*.002	Zr	.0007

Rawson (1963, p. 133) suggested that the lead was derived from a small number of lead bricks that were placed at one point in the buttonhook drift, and that the carbon was derived from the burning of wood left in the buttonhook drift. Yet it hardly seems possible that the small amount of lead left in the buttonhook drift could have had such wide circumferential distribution from a point source. Wood fragments recovered from the breccia were only slightly scorched—not charred—and much of the wire found in the breccia still had uncharred insulation around it. Bags of salt that were only 90 feet from the shotpoint were found with fragments of the cloth still intact (fig. 11*B*), and the cloth showed no evidence of charring. Because of the foregoing evidence, it seems unlikely that materials left in the buttonhook drift could have been the source of the lead and carbon.

There are two possible sources for the melted salt in the vein material. The first of these, of course, is salt directly melted by the heat from the blast. The second is salt produced by shock-induced melting from the free-moving salt near the buttonhook drift. The first source seems more plausible because of the presence of elements that must have come from the device chamber. Moreover, the fact that the lead combined with sulfur and chlorine suggests that those elements were provided by vaporized halite and polyhalite near the device, and, as noted above, the organic materials in the breccia do not appear to have been subjected to heat intense enough to destroy them.

It is postulated, therefore, that the melted salt, as well as the introduced elements, was derived from the vicinity of the device and was injected through fractures that were sealed before any radioactive elements were able to escape. There was no increase in iron content in the postshot rocks. Presumably the iron did not vaporize as early as the other elements [2] and thus was unable to escape.

The lead combined with chlorine from the sodium chloride and with water to form laurionite and with sulfur derived from the sulfate mineral polyhalite to form galena. The presence of the OH radical in the laurionite suggests that the mineral was formed at a temperature less than 142°C, because above that point laurionite breaks down into lead chlorides and lead oxides. Thus, it must have formed approximately in place during retrograde temperature change.

DETAILED DESCRIPTION OF ROCKS IN THE GNOME SHAFT

Section measured in 1961 (preexplosion) by L. M. Gard, Jr., and W. A. Mourant. Color designations are from the Rock-Color Chart (Goddard and others, 1948)

Description	*Thickness (ft)*	*Depth (ft)*
Concrete collar	0.8	0.0 – 0.8
Fill (caliche material used to stabilize area)	.5	.8 – 1.3
Alluvial bolson deposits (Quaternary):		
Sand, moderate-brown (5*YR* 4.5/5), unconsolidated (dune sand); made up of fine to medium subrounded to well-rounded clear and dark-stained quartz grains; contains some quartz crystals with subrounded faces	7.6	1.3 – 8.9
Caliche, white, poorly indurated; contains white calcium carbonate cementing sand like that described above	3.3	8.9 – 12.2
Sand, moderate-brown (5*YR* 4.5/5), unconsolidated; made up of fine to coarse subrounded to well-rounded clear and stained quartz grains; some quartz crystals have subrounded faces; contains some small grains of calcareous cementing material	30.8	12.2 – 43.0
Total thickness of alluvial bolson deposits	43.0	
Gatuna Formation (Pleistocene(?)):		
Sandstone, moderate-brown (5*YR* 4.5/5), very fine grained to medium-grained with pebbles as large as 4 mm, partly indurated; made up of subrounded to well-rounded clear and dark-stained quartz grains; has calcareous cement	2.0	43.0 – 45.0
Conglomerate, pale-red (10*R* 6/2), well-indurated; made up of 20 percent fine to medium sand, 50 percent coarse-grained sand, 30 percent very fine to coarse pebbles of quartzite, limestone, siltstone; has calcareous cement	1.0	45.0 – 46.0
Sandstone, as in 43.0–45.0 ft; contains thin lenses of conglomerate as above	1.7	46.0 – 47.7
Conglomerate, as in 45.0–46.0 ft	.5	47.7 – 48.2
Sandstone, as in 43.0–45.0 ft	.4	48.2 – 48.6
Conglomerate, as in 45.0–46.0 ft	1.3	48.6 – 49.9
Sandstone, as in 43.0–45.0 ft	.6	49.9 – 50.5
Conglomerate, as in 45.0–46.0 ft	.4	50.5 – 50.9
Sandstone, as in 43.0–45.0 ft; contains three lenses (each about 0.05 ft thick) of conglomerate as in 45.0–46.0 ft	2.6	50.9 – 53.5
Conglomerate, as in 45.0–46.0 ft	.6	53.5 – 54.1
Sandstone, as in 43.0–45.0 ft	.6	54.1 – 54.7
Conglomerate, as in 45.0–46.0 ft	.1	54.7 – 54.8
Sandstone, as in 43.0–45.0 ft	.2	54.8 – 55.0
Conglomerate, as in 45.0–46.0 ft	.5	55.0 – 55.5
Sandstone, as in 43.0–45.0 ft	.3	55.5 – 55.8
Conglomerate, as in 45.0–46.0 ft	2.4	55.8 – 58.2
Sandstone, as in 43.0–45.0 ft	2.3	58.2 – 60.5
Conglomerate, as in 45.0–46.0 ft	.8	60.5 – 61.3
Sandstone, as in 43.0–45.0 ft	2.3	61.3 – 63.6
Conglomerate, as in 45.0–46.0 ft	.1	63.6 – 63.7
Sandstone, as in 43.0–45.0 ft	1.8	63.7 – 65.5
Conglomerate, as in 45.0–46.0 ft	.2	65.5 – 65.7
Sandstone, as in 43.0–45.0 ft	.6	65.7 – 66.3
Conglomerate, as in 45.0–46.0 ft	1.8	66.3 – 68.1
Sandstone, as in 43.0–45.0 ft	.7	68.1 – 68.8
Conglomerate, as in 45.0–46.0 ft	.2	68.8 – 69.0
Sandstone, as in 43.0–45.0 ft	3.1	69.0 – 72.1
Conglomerate, as in 45.0–46.0 ft	.1	72.1 – 72.2
Sandstone, as in 43.0–45.0 ft	.6	72.2 – 72.8
Conglomerate, as in 45.0–46.0 ft	.1	72.8 – 72.9
Sandstone, as in 43.0–45.0 ft	.6	72.9 – 73.5
Conglomerate, as in 45.0–46.0 ft	1.3	73.5 – 74.8
Sandstone, as in 43.0–45.0 ft	.5	74.8 – 75.3
Conglomerate, as in 45.0–46.0 ft; contains reworked fragments of red and gray siltstone from Dewey Lake Redbeds	1.0	75.3 – 76.3

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[2] See the following table:

	Melting point (°C)	*Boiling point (°C)*
Iron	1,535	3,000
Tin	231.9	2,270
Silver	960	1,950
Lead	327	1,620
Bismuth	271	1,560±5
Salt	801	1,413
Zinc	419	907

Description	*Thickness (ft)*	*Depth (ft)*
Gatuna Formation (Pleistocene (?))—Continued		
Sandstone, as in 43.0–45.0 ft; contains reworked fragments of red and gray siltstone from Dewey Lake Redbeds	.4	76.3 – 76.7
Conglomerate, as in 45.0–46.0 ft; contains reworked fragments of red and gray siltstone from Dewey Lake Redbeds	1.7	76.7 – 78.4
Clay, pale-reddish-brown (10*R* 5/4), very hard, dense; contains interwoven black carbonaceous material	.1	78.4 – 78.5
Sandstone, as in 43.0–45.0 ft	1.0	78.5 – 79.5
Clay, as in 78.4–78.5 ft	.1	79.5 – 79.6
Sandstone, as in 43.0–45.0 ft	1.0	79.6 – 80.6
Clay, as in 78.4–78.5 ft	.05	80.6 – 80.65
Sandstone, as in 43.0–45.0 ft	.75	80.65– 81.4
Sandstone, as in 43.0–45.0 ft; contains many thin lenses of clay (about 0.01 ft. thick) as described in 78.4–78.5 ft	4.1	81.4 – 85.5
Sand, pale-reddish-brown (10*R* 5/4), very fine grained to coarse-grained, subrounded to well-rounded, unconsolidated; contains a few large yellow-green quartz pebbles and clear and stained quartz grains, a few quartz crystals with subrounded faces, some small grains of calcareous cementing material, and reworked fragments of Dewey Lake Redbeds	6.4	85.5 – 91.9
Total thickness of Gatuna Formation	48.9	
Unconformity.		
Dewey Lake Redbeds (Upper Permian):		
Siltstone, sandy, pale-reddish-brown (10*R* 5/4), well-indurated; contains light-greenish-gray (5*GY* 8/1), reduction spots and fine silt; calcite crystals and clusters dispersed throughout rock; has calcareous cement	1.7	91.9 – 93.6
Siltstone, as above except contains some clayey layers	3.7	93.6 – 97.3
Clay, pale-reddish-brown (10*R* 5/4), very dense; contains interspreed black carbon spots, and silty streaks containing reduction spots	.1	97.3 – 97.4
Siltstone, as in 91.9–93.6 ft	4.6	97.4 – 102.0
Siltstone, light-greenish-gray (5*GY* 8/1), fine-grained, well-indurated; contains calcite crystals in clusters and interspersed throughout rock; has calcareous cement	.4	102.0 – 102.4
Siltstone, as in 91.9–93.6 ft	3.6	102.4 – 106.0
Siltstone, as above but darker and finer grained; contains lenses of white very fine grained sandstone	.7	106.0 – 106.7
Siltstone, as in 91.9–93.6 ft	4.3	106.7 – 111.0
Siltstone, as in 91.9–93.6 ft. but contains thin wavy bands of gray siltstone which extend around shaft	1.1	111.0 – 112.1
Dewey Lake Redbeds (Upper Permian)—Continued		
Siltstone, pale-reddish-brown (10*R* 5/4), well-indurated, mostly thin-bedded; contains light-greenish-gray (5*GY* 8/1) reduction spots; calcite crystals in clusters dispersed throughout rock and fill joints; contains thin bands of clay or clayey material and black spots of manganese or oil(?) in joints and porous strata; has calcareous cement	10.5	112.1 – 122.6
Siltstone, same as above but contains thin lenses of sandstone	8.1	122.6 – 130.7
Siltstone, as in 102.0–102.4 ft	.4	130.7 – 131.1
Siltstone, as in 122.6–130.7 ft; contains 0.5-ft-thick layers of siltstone as in 102.0–102.4 ft	13.9	131.1 – 145.0
Siltstone, same as above; contains 1-mm-thick bands of selenite crystals	8.0	145.0 – 153.0
Siltstone, sandy, pale-reddish-brown (10*R* 5/4), well-indurated to very friable; contains light-greenish-gray (5*GY* 8/1) reduction spots and thin layers; sand grains well rounded; has calcareous cement	16.0	153.0 – 169.0
Siltstone, as in 112.1–122.6 ft; jointing in interval 169–133 ft, as follows: Strike N. 70° W., dip 75° N.; strike N. 20° W., dip approximately 85° E.; bedding strikes N. 45° E., dips 4° NW; reduction spots in vertical zone tapering from 8 to 0 in.; apparently following fractures; from 175 to 178 ft, some reduction spots 1 ft in diameter; joints at 200 ft strike N. 30° W., dip 70° NE.; joints at 216 ft strike N. 90° E., dip 75° N.; calcite fills veins; joints at 278–284 ft strike N. 30° W., dip 50° N. to vertical	125.0	169.0 – 294.0
Total thickness of Dewey Lake Redbeds	202.1	
Unconformity.		
Rustler Formation (Upper Permian):		
Forty-niner Member:		
Gypsum rock, white (*N* 9) to olive-gray (5*Y* 5/1); crystals 1–5 mm long; upper contact, with the Dewey Lake Redbeds at 294 ft, undulating and marked by green clay seam about 0.5 in. thick underlain by gray clay layer about 0.06 in. thick between red beds and white gypsum; gypsum grades into anhydrite from 298 to 300 ft with no definite contact, either laterally or vertically	6.0	294.0 – 300.0

Description	*Thickness (ft)*	*Depth (ft)*
Rustler Formation (Upper Permian)—Continued		
Forty-niner Member—Continued		
Anhydrite rock, olive-gray (5*Y* 5/1), massive, crystalline; contains some gypsum crystals; grades into gypsum above and below; white and pink fibrous gypsum and many fractures present at 315 ft; slickensides present at 316 ft	22.0	300.0 – 322.0
Gypsum rock, white (*N* 9) to olive-gray (5*Y* 5/1), massive, crystalline; contains white and pink fibrous gypsum at 325 ft and white and gray bands throughout	6.5	322.0 – 328.4
Siltstone, greenish-gray (5*GY* 7/1); well-indurated; has calcareous cement	.2	328.4 – 328.6
Siltstone, sandy, pale-reddish-brown (10*R* 5/4), well-indurated to friable; contains some brecciated layers, fragments of gypsum, and light-greenish-gray reduction spots; has mostly calcareous cement; some clay lenses	11.0	328.6 – 339.6
Gypsum, breccia, grayish-red (10*R* 4/2) well-indurated; contains 1- to 2-cm long fragments of clear, red, and gray gypsum and fragments of gray and red siltstone; has calcareous cement	1.0	339.6 – 340.6
Gypsum rock, banded, pinkish-gray (5*YR* 8/1) and pale-red (10*R* 6/2), massive, crystalline; gradational with breccia above; red bands appear to be stylolitic; some patches of anhydrite grade into gypsum in lower 10 ft; lower 6 ft has 1-cm-thick fibrous veins of white gypsum approximately parallel to the bedding and about 5 cm apart; gypsum breccia at 359 ft	20.7	340.6 – 361.3
Total thickness of Forty-niner Member	67.3	
Magenta Member:		
Dolomite rock, red-purple (magenta) (5*RP* 5/2), massive; contains white 1-mm-thick bands of selenite about 1 cm apart and scattered crystals of selenite in dolomite; cement dolomitic or calcareous; has fractures 1–5 cm wide filled with selenite	6.8	361.3 – 368.1
Siltstone, light-brownish-gray (5*YR* 6/1) to moderate-red (5*Y* 5/4); layers of siltstone alternate with irregular bands of selenite; has dolomitic or calcareous cement; beds range from paper thin to 0.5 ft thick	3.6	368.1 – 371.7
Rustler Formation (Upper Permian)—Continued		
Magenta Member—Continued		
Dolomite rock, silty, gypsiferous, pale-red (5*R* 6/2) to light-gray (*N* 7), thin-bedded; contains 1-mm to 1-cm-thick wavy bands of fibrous gypsum parallel to bedding; has wavy botryoidal bedding in lower 6 ft; joints strike N. 90° E., dip 84° N., and strike N. 10° E., dip 84° W.; bedding strikes north, dips 7° E; cluster of black manganese(?) in red and colorless fibrous gypsum at 379 ft	10.5	371.7 – 382.2
Total thickness of Magenta Member	20.9	
Tamarisk Member:		
Anhydrite rock and gypsum rock, pale-red (10*R* 6/2) to light-olive-gray (5*Y* 6/1); contains 1-cm-thick bands of fibrous gypsum parallel to bedding; anhydrite grades into gypsum; some small irregular masses of gypsum throughout massive anhydrite rock microcrystalline; 1-cm-thick red clay layer at 403.5 ft in north wall of shaft; joint sets at 410–416 ft: strike N. 5° W., dip 75° W.; strike N. 25° E., dip 55° SE.; strike N. 90° E., dip 65° N.; strike N. 25° E., dip 55° NW.; joints cemented with selenite; joints at 432–438 ft strike N. 20° W. and dip 45° NE	66.3	382.2 – 448.5
Clay, brownish-black (5*YR* 2/1); plastic, slickensided; contains irregular fragments of fibrous gypsum; thickness ranges from 0.01 to 0.2 ft; dips 36° N. in shaft; this layer is at 440.5 ft in south wall	.1	448.5 – 448.6
Anhydrite rock and gypsum rock, light-olive-gray (5*Y* 6/1); anhydrite and gypsum intergrade; massive anhydrite rock microcrystalline; contains large masses of fibrous and tabular gypsum; joint system strikes N. 55° E., dips 70° N.; folds in gypsum at 472–477 ft; a few thin gray plastic clay seams in gypsum at 477–480 ft	31.4	448.6 – 480.0
Clay, plastic, grayish-red (10*R* 4/2); interbedded gypsum fragments and crystals; selenite veins fill joints and occur along bedding; some cement grout in with selenite and clay; a few gray plastic clay seams at 484 ft; ground water seeps through wall, that has no visible openings	5.0	480.0 – 485.0

Description	*Thickness (ft)*	*Depth (ft)*
Rustler Formation (Upper Permian)—Continued		
Tamarisk Member—Continued		
Anhydrite rock and gypsum rock, light-olive-gray (5*Y* 6/1), banded; 2-in.-thick gray clay seam at 489 ft; contains thin bands of selenite	10.5	485.0 - 495.5
Total thickness of Tamarisk Member	113.3	
Culebra Dolomite Member:		
Dolomite rock, dark-yellowish-brown (10*YR* 4/2), vesicular and vuggy, well-indurated; openings contain calcite crystals	.5	495.5 - 496.0
Dolomite rock, yellowish-gray (5*Y* 8/1), microcrystalline, highly fractured, few vugs, poorly indurated	3.3	496.0 - 499.3
Dolomite rock, yellowish-gray (5*Y* 8/1), microcrystalline; contains brecciated zones, some of which fill vertical fractures; breccia recemented with pale-yellowish-brown (10*YR* 6/2) dolomite, mostly well indurated; contains zones of vesicular or "worm-eaten" dolomite, some of which are highly fractured; cement and chemical grout fill some openings; most vesicles spherical and range in diameter from a pinhead to about 1 inch; most openings not interconnected; some massive zones do not contain any openings	24.2	499.3 - 523.5
Total thickness of Culebra Dolomite Member	28.0	
Lower member:		
Siltstone, medium-dark-gray (*N* 4), clayey, semiplastic; contains dolomite fragments from overlying unit	1.7	523.5 - 525.2
Clay, grayish-red (10*R* 4/2), very plastic; contains fragments and large breccia blocks from overlying units and grout; gypsum fragments mixed through the clay, and this mixture fills many openings in the dolomite; selenite band 0.5 in. thick at 527–530 ft	9.3	525.2 - 534.5
Gypsum rock and anhydrite rock, light-olive-gray (5*Y* 6/1), crystalline, massive; contains a few silty layers; some platy gypsum; beds strike N. 60° E., dip 16° NW.; joints strike N. 30° W., dip 86° S. at 541 ft; gray clay on south wall at 547 ft; beds strike N. 45° E., dip 10° NW. at 541–549 ft	13.1	534.5 - 547.6
Rustler Formation (Upper Permian)—Continued		
Lower member—Continued		
Claystone, grayish-red (10*R* 4/2) and light-gray (*N* 7), plastic; contains alternating layers of red and gray and gypsum bands and gypsum nodules; gray claystone very plastic and in irregular bands in red claystone; has some reduction zones; claystone absorbs water readily	11.5	547.6 - 559.1
Gypsum rock and anhydrite rock, as in 534.5–547.6 ft	3.9	559.1 - 563.0
Claystone, silty, moderate-reddish-brown (10*R* 4/6), poorly indurated; contact irregular, dips NW	3.0	563.0 - 565.0
Siltstone, clayey, sandy, grayish-red (10*R* 4/2); contains alternate discontinuous bands of light-olive-gray (5*Y* 6/1) gypsum; siltstone contains small selenite crystals and blebs of gypsum; no jointing obvious, bedding dips about 10° NW.; lens of gypsum and anhydrite 4 ft long and 1 ft thick at 564 ft in northwest wall	6.0	565.0 - 571.0
Gypsum rock, olive-gray (5*Y* 4/1), massive, crystalline, banded; beds dip about 10°–15° NW. in most of shaft but dip as much as 42° NW. in northwest wall	1.0	571.0 - 572.0
Siltstone, clayey, dark-reddish-brown (10*R* 3/4) and greenish-gray (5*GY* 5/1), laminated, noncalcareous; contains alternating layers of brown and gray; unconsolidated except for some partly consolidated lenses about 0.5 ft thick; more plastic from 577 to 579 ft; bedding dips northwest; sides of shaft spall off	20.0	572.0 - 592.0
Siltstone, clayey, sandy, olive-gray (5*Y* 5/1), very fine grained, poorly indurated, friable; contains blebs of gypsum crystals; shows crenulated wavy bedding, tends to spall off wall in some zones; a few zones fairly well indurated; rock predominantly angular to subrounded silt-size quartz but contains about 1 percent mafic minerals; rock disaggregates with effervescence in dilute HCl; bottom 2 ft of this unit fairly well indurated	59.2	592.0 - 651.2
Total thickness of lower member	127.7	
Total thickness of Rustler Formation	357.2	

Description	*Thickness (ft)*	*Depth (ft)*
Salado Formation (Upper Permian):		
Contact with Rustler Formation unconformable and very irregular. Top of Salado at 647.5 ft at southeast wall of shaft and at 660.0 ft at west wall of shaft.		
Claystone breccia, grayish-red (10*R* 4/2 to 5/2); contains angular and subrounded fragments and blocks of gray siltstone, gypsum, and polyhalite ranging from sand size to 3 ft; contains discontinuous beds of gypsum and veins of fibrous gypsum; has sones of plastic red clay at 680–684 ft that taste salty	36.0	651.2 – 687.2
Claystone, medium-gray (*N* 5), plastic; contains abundant fragments and veins of colorless crystalline gypsum or selenite	.4	687.2 – 687.6
Polyhalite rock, dark-reddish-brown (10*R* 3/4), crystalline, massive, platy; strikes N. 50° E., dip 18° NW	.9	687.6 – 688.5
Siltstone, clayey, sandy, grayish-red (10*R* 4/2), calcareous; contains fragments of colorless crystalline gypsum	.3	688.5 – 688.8
Claystone, plastic, poorly indurated; consists of very thin bands of dark-gray and grayish-red claystone containing veins and fragments of colorless crystalline gypsum	.4	688.8 – 689.2
Siltstone, clayey, grayish-red (10*R* 5/2), calcareous; contains small amount of tiny fragments of clear gypsum and fragments of polyhalite	4.3	689.2 – 693.5
Gypsum rock, very pale orange (10*YR* 8/2) to light-brown (5*YR* 6/4), massive, microcrystalline; shows irregular stains of light-brown clay	.5	693.5 – 694.0
Anhydrite rock, olive-gray (5*Y* 5/1), microcrystalline, massive	12.0	694.0 – 706.0
Claystone, medium-dark-gray (*N* 4), plastic; contains poorly indurated blocks of anhydrite	2.0	706.0 – 708.0
Anhydrite rock, olive-gray (5*Y* 4/1), massive microcrystalline; shows conchoidal fracture; bedding dips 5° NW	1.2	708.0 – 709.2
Claystone, light-gray (*N* 7), banded, well-indurated; probably alteration product of anhydrite above; interbedded with halite below	.1	709.2 – 709.3
Halite rock, colorless to white; contains small blebs of moderate-reddish-orange (19*R* 6/7) halite and less than 1 percent gray clay	1.7	709.3 – 711.0
Halite rock, colorless to white; contains less than 1 percent small blebs of moderate-red (5*R* 4/6) clay	4.5	711.0 – 715.5
Claystone, pale-reddish-brown (10*R* 5/4) and light-gray (*N* 7); dips west at less than 1°; contains about 25 percent halite	.5	715.5 – 716.0
Salado Formation (Upper Permian)—Continued		
Halite rock; contains about 50 percent dark-reddish-brown (10*R* 3/4) clay	3.5	716.0 – 719.5
Halite rock; contains about 10 percent medium-light-gray (*N* 6) clay	1.5	719.5 – 721.0
Halite rock, colorless to white	1.7	721.0 – 722.7
Halite rock; contains about 5 percent medium-light-gray (*N* 6) clay; has irregular band of dark-reddish-brown (10*R* 3/4) clay at top which ranges from 0 to 1 ft thick	2.5	722.7 – 725.2
Claystone, plastic, dark-reddish-brown (10*R* 4/4) and medium-gray (*N* 5)	.4	725.2 – 725.6
Halite rock, colorless; contains about 5 percent medium-gray (*N* 5) clay	1.9	725.6 – 727.5
Halite rock, colorless; contains blebs and spots of reddish-orange (10*R* 6/7) halite; contains less than 2 percent medium-gray (*N* 5) clay	3.8	727.5 – 731.3
Claystone, medium-dark-gray (*N* 4); irregular in thickness	.2	731.3 – 731.5
Halite, colorless to white; contains some blebs of reddish-orange halite; thin discontinuous clay layer in lower 1 ft; clay content less than 1 percent	9.7	731.5 – 741.2
Polyhalite rock, orange	.7	741.2 – 741.9
Halite rock, reddish-orange (10*R* 6/7) to transparent white; at 742.6 ft contains 1.2-ft-thick reddish-brown clay layer	6.0	741.9 – 747.0
Halite rock, 5–10 percent reddish-brown clay; upper 2 ft contains 50 percent brown clay; unit contains several thin discontinuous clay seams and stringers and blebs of moderate-reddish-orange (10*R* 5/6) polyhalite	13.1	747.9 – 761.0
Halite rock; contains medium-gray clay band 0.1 ft thick at 762.0 ft, and dark-reddish-brown clay band 0.3 ft thick at 763.3 ft; above gray clay band is a double band of polyhalite separated by transparent colorless halite 0.2 ft thick (marker horizon(?))	5.0	761.0 – 766.0
Halite rock, transparent colorless; contains three bands of thin moderate-orange-pink (10*R* 7/4) polyhalite	.9	766.0 – 766.9
Halite rock, colorless transparent to white; contains blebs of moderate-orange-pink halite	2.3	766.0 – 769.2
Polyhalite rock, moderate-orange-pink (10*R* 7/4); contains 0.2-in.-thick band of halite in middle	.3	769.2 – 769.5
Halite rock, white; contains less than 1 percent moderate-gray clay; some polyhalite blebs and stringers scattered throughout lower half	4.1	769.5 – 773.6
Claystone, dark-reddish-brown (10*R* 3/4), plastic; contains scattered crystals of halite; 0.5-in.-thick gray layer at top	1.2	773.6 – 774.8

Description	*Thickness (ft)*	*Depth (ft)*
Salado Formation (Upper Permian)—Continued		
Halite rock; contains about 20 percent dark-reddish-brown clay; grades into overlying unit; irregular and discontinuous polyhalite band at 776.6 ft that averages 0.2 ft thick	6.3	774.8 – 781.1
Claystone, dark-reddish-brown (10*R* 3/4); dips less than 1° NW	.1	781.1 – 781.2
Halite rock; contains about 35 percent dark-reddish-brown clay in blebs and discontinuous bands; contains about 2 percent polyhalite in blebs	4.4	781.2 – 785.6
Polyhalite rock about 0.1 ft thick overlying 0.1 ft of gray anhydrite rock	.2	785.6 – 785.8
Halite rock; contains about 10–20 percent polyhalite in blebs and stringers and about 5 percent gray clay	9.7	785.8 – 795.5
Polyhalite rock; moderate-orange-pink (10*R* 7,4); contains 1-mm-thick discontinuous dark-gray clay band in middle	1.4	795.5 – 796.9
Claystone, medium-light-gray (*N* 6); contains about 20 percent halite	.3	796.9 – 797.2
Halite rock, moderate-reddish-orange (10*R* 6 6); contains about 20 percent gray clay	.8	797.2 – 798.0
Claystone, dark-reddish-brown; contains about 50 percent halite	6.0	798.0 – 804.0
Halite rock; upper 5 ft contains about 10–20 percent gray clay in blebs; lower 6 ft contains about 2 percent polyhalite in discontinuous stringers and blebs	9.3	804.0 – 813.3
Halite rock; contains about 20 percent polyhalite in blebs, stringers, and irregular masses	5.2	813.3 – 818.5
Claystone, medium-dark-gray (*N* 4) to medium-light-gray (*N* 6); contains about 25 percent halite	2.1	818.5 – 820.6
Claystone, same as next higher unit but contains about 10 percent polyhalite	2.0	820.6 – 822.6
Anhydrite rock, yellowish-gray (5*Y* 8/1), banded, vuggy; contains about 5 percent halite; some polyhalite blebs at top	2.4	822.6 – 825.0
Anhydrite rock, banded with gypsum and halite; gypsum and halite are dusky yellow (5*Y* 6/4); anhydrite is light gray (*N* 7); in other walls of shaft, more than 1 ft of polyhalite underlies this unit, but it pinches out and is absent from north wall	2.5	825.0 – 827.5
Claystone, medium-gray (*N* 5), plastic	.5	827.5 – 828.0
Halite rock, transparent, colorless; contains about 5 percent gray clay in blebs and about 2 percent polyhalite	3.3	828.0 – 831.3
Anhydrite rock, light-gray (*N* 7)	.2	831.3 – 831.5
Halite rock; contains about 20 percent polyhalite that occurs in discontinuous bands	1.5	831.5 – 833.0
Anhydrite rock, very light gray (*N* 8); banded upper foot contains some halite and polyhalite in discontinuous bands 0.8 ft thick	2.5	833.0 – 835.5
Halite rock, colorless to white; contains about 1 percent polyhalite in blebs and one band of anhydrite 1 in. thick	1.3	835.5 – 836.8
Anhydrite rock, very light gray (*N* 8), microcrystalline	.4	836.8 – 837.2
Halite rock; contains a 1-mm-thick band of anhydrite and more than 1 percent gray clay in blebs	.8	837.2 – 838.0
Anhydrite rock, very light gray (*N* 8), laminated; at 839.2–838.4 ft, contains breccia layer consisting of anhydrite fragments in clay matrix; at 839.8–840.1 ft, contains band of moderate-orange-pink (10*R* 7/4) to white halite; basal 0.3 ft contains gray clay and orange-pink halite	6.3	838.0 – 844.3
Halite, rock transparent, colorless;contains about 1 percent gray clay blebs	6.9	844.3 – 851.2
Claystone, medium-dark-gray (*N* 4); contains 2-mm-thick discontinuous bands of halite	.7	851.2 – 851.9
Halite rock, transparent, colorless to moderate-orange-pink; contains about 20 percent medium-gray (*N* 5) and dark-reddish-brown (10*R* 3/4) clay in blebs and 5 percent moderate-orange-pink (10*R* 7/4) polyhalite	1.1	851.9 – 853.0
Halite rock, transparent, colorless to white; contains about 6 percent polyhalite in blebs	1.9	853.0 – 854.9
Halite rock; contains about 30–50 percent dark-reddish-brown (10*R* 3/4) clay	1.5	854.9 – 856.4
Halite rock, transparent, colorless to white; contains about 10 percent greenish-gray (5*GY* 6/1) clay in blebs and 1 percent polyhalite in blebs	5.3	856.4 – 861.7
Halite rock, transparent, colorless to white; contains about 2 percent medium-gray (*N* 5) clay and less than 1 percent polyhalite, both in blebs; separated from overlying unit by distinct change in amount of clay	5.6	861.7 – 867.3
Halite rock, white; contains about 5 percent medium-gray (*N* 5) clay and about 1 percent polyhalite in blebs; drill holes in sump at 874 ft have gas bubbling up	9.4	867.3 – 876.7
Polyhalite rock, moderate-reddish-orange (10*R* 6/6); contains about 25 percent halite	1.8	876.7 – 878.5
Claystone, light-gray (*N* 7); contains about 50 percent halite	1.5	878.5 – 880.0
Claystone, dark-reddish-brown (10*R* 3/4); contains about 25 percent halite	1.5	880.0 – 881.5

Description	*Thickness (ft)*	*Depth (ft)*
Salado Formation (Upper Permian)—Continued		
Halite rock, colorless to orange; contains about 40 percent clay, both grayish red (10*R* 4/2) and greenish gray (5*GY* 6/1), and about 5 percent polyhalite in blebs	5.0	881.5 - 886.5
Polyhalite rock, moderate-reddish-orange (10*R* 6/6)	1.0	886.5 - 887.5
Halite rock, white to moderate-orange; upper foot contains about 5 percent light-gray (*N* 7) clay; remainder contains less than 1 percent clay; a discontinuous polyhalite bed at 895.5 ft averages 2 in. thick	10.0	887.5 - 897.5
Polyhalite rock, grayish-orange-pink (10*R* 8/2)	.3	897.5 - 897.8
Halite rock, white; contains about 10 percent medium-gray (*N* 5) clay	.7	897.8 - 898.5
Halite rock, moderate-reddish-orange (10*R* 6/6); contains 1 percent polyhalite in blebs near base	2.3	898.5 - 900.8
Halite rock, moderate-reddish-orange (10*R* 6/6); contains about 25 percent medium-gray (*N* 5) clay in bands; has 2-in.-thick band of dark-reddish-brown (10*R* 3/4) clay at base	1.5	900.8 - 902.3
Halite rock, transparent, colorless; contains about 30 percent dark-reddish-brown (10*R* 3/4) clay	1.7	902.3 - 904.0
Halite rock, white; contains about 10 percent greenish-gray (5*GY* 6/1) clay in blebs and bands; contains about 1 percent polyhalite in blebs	8.1	904.0 - 912.1
Halite rock, clear; contains about 25 percent medium-light-gray (*N* 6) clay	.6	912.1 - 912.7
Halite rock, transparent, colorless to moderate-orange-pink (10*R* 7/4); contains discontinuous 1-in.-thick bands of polyhalite	2.0	912.7 - 914.7
Polyhalite rock, moderate-reddish-orange (10*R* 6/6); contains irregular discontinuous bands of transparent, colorless halite	.7	914.7 - 915.4
Claystone, medium-light-gray (*N* 6); thickness ranges from featheredge to 0.2 ft	.2	915.4 - 915.6
Halite rock; contains about 2 percent gray clay and about 1 percent polyhalite in blebs	4.2	915.6 - 919.8
Halite rock; contains about 20 percent of both gray and reddish-brown clay and about 10 percent polyhalite; 0.2-ft-thick bed of polyhalite present at 920 ft	1.2	919.8 - 921.0
Halite rock; contains about 5 percent gray clay in blebs and about 2 percent polyhalite in blebs	6.6	921.0 - 927.6
Halite rock; contains about 10 percent polyhalite in blebs and bands; bottom 1 foot contains about 50 percent polyhalite in alternating bands with halite	3.9	927.6 - 931.5
Claystone, dark-reddish-brown (10*R* 3/4); contains about 40 percent halite	1.5	931.5 - 933.0
Halite rock; contains about 10 percent medium-gray (*N* 5) clay and about 5 percent polyhalite in blebs and discontinuous layers	10.2	933.0 - 943.2
Polyhalite rock in layers 0.1–0.3 ft thick alternating with halite	1.8	943.2 - 945.0
Halite rock, white; contains less than 1 percent polyhalite in blebs	2.5	945.0 - 947.5
Halite rock, moderate-reddish-orange (10*R* 6/6); appears to be layered in about 0.5-ft-thick layers owing to variations in color; contains thin (1 mm) bands of white opaque halite; becomes darker orange near base	8.0	947.5 - 955.5
Polyhalite rock; lower half contains thin (2 mm) bands of clay	1.0	955.5 - 956.5
Halite rock; contains about 1 percent polyhalite in blebs; contains about 5 percent gray clay from 960 to 960.7 ft	2.5	956.5 - 959.0
Claystone, medium-dark-gray (*N* 4); contains about 50 percent halite	1.0	959.0 - 960.0
Claystone, dark-reddish-brown (10*R* 3/4); contains about 50 percent halite	3.0	960.0 - 963.0
Halite rock; contains about 20 percent dark-reddish-brown (10*R* 3/4) clay and about 5 percent polyhalite in blebs	1.0	963.0 - 964.0
Halite rock; contains about 25 percent polyhalite	1.5	964.0 - 965.5
Anhydrite rock, yellowish-gray (5*Y* 8/1), dense, fine-grained; contains crystalline grayish-orange (10*YR* 7/4) anhydrite	1.5	965.0 - 967.0
Halite rock, transparent, colorless to white; contains 0.1- to 0.2-ft-thick bands of polyhalite separated by 0.2- to 1-ft-thick layers of halite	5.7	967.0 - 972.7
Polyhalite rock, moderate-reddish-orange (10*R* 6/6)	.4	972.7 - 973.1
Anhydrite rock, yellowish-gray (5*Y* 8/1), banded in 0.5-in.-thick layers	.9	973.1 - 974.0
Halite rock, colorless to white; contains about 10–20 percent polyhalite in blebs and thin layers, and about 2 percent gray clay in blebs; 0.2-ft-thick discontinuous layer of polyhalite present at 981.5 ft	11.2	974.0 - 985.2
Halite rock; contains about 10 percent medium-dark-gray (*N* 4) clay and 1 percent polyhalite; has 0.2-ft-thick bed of medium-dark-gray clay at base	1.4	985.2 - 986.6
Halite rock; contains about 50 percent dark-reddish-brown (10*R* 4/6) clay	3.4	986.6 - 990.0
Halite rock; contains thin bands of polyhalite	2.8	990.0 - 992.8

Description	*Thickness (ft)*	*Depth (ft)*
Salado Formation (Upper Permian)—Continued		
Polyhalite rock, moderate-red (5*R* 5/4)	0.1	992.8 – 992.9
Halite rock, transparent, colorless; contains about 10–15 percent greenish-gray (5*G* 6/1) clay in irregular layers and about 2 percent polyhalite in blebs; halite coarsely crystalline, occurring as 1-in. crystals	7.6	992.9 –1,000.5
Halite rock, white to colorless, transparent; contains less than 1 percent polyhalite in thin irregular streaks	2.5	1,000.5 –1,003.0
Polyhalite rock, grayish-orange-pink (*YR* 7/2), banded; from 1,003 to 1,004 ft consists mainly of polyhalite and halite with some anhydrite bands; anhydrite is microcrystalline and spalls and shatters when struck. One joint set strikes N. 50° E., dips 65° NW.; another set is normal to this; joints spaced about 0.5 ft apart	4.0	1,003.0 –1,007.0
Anhydrite rock, light-olive-gray (5*Y* 6/1), banded in ¼-in.-thick bands; basal 0.5 ft contains medium-gray clay (*N* 5) and gypsum	2.2	1,007.0 –1,009.2
Halite rock, transparent, colorless to moderate-reddish-orange; contains about 2 percent polyhalite in blebs	3.1	1,009.2 –1,012.3
Polyhalite rock, pale-reddish-brown (10*R* 5/4); contains several thin gray clay seams	1.7	1,012.3 –1,014.0
Halite rock, medium-light-gray (*N* 6); contains about 10 percent clay	.9	1,014.0 –1,014.9
Halite rock; in alternating white and pale-yellowish-orange (10*YR* 8/6) bands 0.2–0.3 ft thick	5.9	1,014.9 –1,020.8
Halite rock; alternates with irregular bands of silty dark-reddish-brown (10*R* 3/4) clay; contains about 50 percent clay; contains 2 percent polyhalite in blebs near top of unit	3.5	1,020.8 –1,024.3
Siltstone, clayey, pale-reddish-brown (10*R* 5/4); contains light-gray (*N* 7) clay blebs. (With subjacent unit is Vaca Triste Sandstone Member of Adams (1944).)	2.0	1,024.3 –1,026.3
Siltstone, clayey, pale-reddish-brown (10*R* 5/4); contains about 50 percent halite	2.7	1,026.3 –1,029.0
Halite rock; top 3 ft contains about 40 percent dark-reddish-brown (10*R* 3/4) clay; basal 2 ft contains about 5 percent polyhalite in blebs and stringers	5.7	1,029.0 –1,034.7
Halite rock; contains about 20 percent light-gray (*N* 7) clay	1.4	1,034.7 –1,036.1
Halite rock, transparent, colorless; contains about 10 percent polyhalite in irregular layers and blebs	3.5	1,036.1 –1,039.6
Halite rock; contains about 10 percent light-gray (*N* 7) clay in irregular thin bands and blebs	0.9	1,039.6 –1,040.5
Halite rock, transparent, colorless; contains about 5 percent polyhalite in irregular horizontal stringers and blebs; contains 1-cm-thick band of light-gray (*N* 7) clay at 1,043.3 ft	4.0	1,040.5 –1,044.5
Claystone, light-gray (*N* 7); contains about 50 percent halite; has 0.1-ft-thick layer of dark-reddish-brown (10*R* 3/4) clay at base	2.1	1,044.5 –1,046.6
Halite rock, white to colorless, transparent; contains about 10 percent polyhalite in blebs; irregular clayey zone present at 1,057 ft; interval 1,053–1,057 ft contains about 2 percent polyhalite in discontinuous layers; irregular band of gray clay at base averages 0.05 ft thick	10.4	1,046.6 –1,057.0
Claystone, dark-reddish-brown (10*R* 3/4); contains about 30–40 percent halite; discontinuous gray clay layers at top	2.0	1,057.0 –1,059.0
Halite rock, white to colorless; contains about 1 percent polyhalite in blebs and thin bands and about 10–20 percent of both red and gray clay in irregular bands and disseminated blebs; layer at 1,061–1,063 ft contains about 40 percent clay; unit contains gas under pressure	5.3	1,059.0 –1,064.3
Polyhalite rock; underlain by 0.5 in. light-gray (*N* 7) clay	.2	1,064.3 –1,064.5
Halite rock; contains about 5 percent polyhalite in stringers and blebs	2.8	1,064.5 –1,067.3
Claystone, pale-red (10*R* 6/2); top 0.2 ft light-gray (*N* 7) clay; unit contains about 5 percent halite; gas present in this unit	3.7	1,067.3 –1,071.0
Halite rock, white to colorless; contains less than 1 percent polyhalite in blebs and less than 1 percent red clay in blebs	3.5	1,071.0 –1,074.5
Halite rock, transparent, colorless; contains about 5 percent polyhalite in irregular discontinuous bands; contains a few 2-mm-thick layers of brown clay at 1,078–1,083.4 ft	9.0	1,074.5 –1,083.5
Halite rock; contains about 25 percent medium-light-gray (*N* 6) clay	.9	1,083.5 –1,084.4
Halite rock; contains about 40 percent pale-reddish-brown (10*R* 5/4) clay; basal contact irregular	4.6	1,084.4 –1,089.0
Halite rock; contains about 10 percent polyhalite in irregular horizontal bands about 1 in. thick; upper part of unit contains vertical stringers of medium-gray (*N* 5) clay	7.0	1,089.0 –1,096.0

Description	*Thickness (ft)*	*Depth (ft)*
Salado Formation (Upper Permian—Continued		
Polyhalite rock; upper half contains about 10 percent halite in blebs	1.0	1,096.0-1,097.0
Polyhalite rock, banded; 0.2-ft-thick medium-gray (*N* 5) clay layer at base	1.6	1,097.0-1,098.6
Halite rock, colorless to white; contains less than 1 percent polyhalite in blebs and less than 1 percent gray clay in blebs	11.7	1,098.6-1,110.3
Halite rock; contains about 30–50 percent pale-reddish-brown (10*R* 5/4) clay, and contains about 1 percent polyhalite in blebs near top; clay in top and bottom 1 foot is gray	5.2	1,110.3-1,115.5
Halite rock, colorless to white; contains 10–20 percent stringers and blebs of polyhalite; 0.1-ft-thick layer of polyhalite underlain by 0.05-ft-thick layer of gray clay at base	1.9	1,115.5-1,117.4
Halite rock; contains about 25 percent medium-light-gray (*N* 6) clay in upper part; basal 2 ft contains no clay	2.9	1,117.4-1,120.3
Anhydrite rock; in alternating grayish-orange (10*YR* 7/4) and very light gray (*N* 8) bands; contains scattered blebs and lenses of polyhalite and halite; 0.2-ft-thick gray clay layer at base	3.9	1,120.3-1,124.2
Halite rock, colorless to moderate-reddish-orange (10*R* 6/6); contains a band of grayish-orange-pink (5*YR* 7/2) anhydrite from 1,125.5 to 1,125.8 ft; contains gas	3.1	1,124.2-1,127.3
Polyhalite rock, banded, grayish-orange-pink (5*YR* 7/2); 0.05 ft of gray clay at base	.5	1,127.3-1,127.8
Halite rock, in alternating white and moderate-reddish-orange (10*R* 6/6) bands; contains discontinuous clayey zones near top and base	3.0	1,127.8-1,130.8
Claystone, grayish-red (10*R* 4/2); contains about 30 percent halite; 0.05-ft-thick layer of gray clay at top; contains irregular bands of polyhalite and halite in interval 1,131.2–1,131.8 ft	4.0	1,130.8-1,134.8
Halite rock; contains about 50 percent polyhalite and about 10 percent gray clay	1.0	1,134.8-1,135.8
Claystone, greenish-gray (5*GY* 6/1); contains about 50 percent halite, and inclusions of grayish-red (10*R* 4/2) clay; lower contact gradational	2.0	1,135.8-1,137.8
Halite rock, transparent colorless; contains vaguely defined bands of moderate-reddish-orange (10*R* 6/5) halite and 2- to 4-mm-thick bands of anhydrite in the lower half	18.2	1,137.8-1,156.0
Polyhalite rock, moderate-reddish-brown (10*R* 4/6); contains several plastic medium-gray (*N* 5) clay layers 2–5 mm thick; contains lenses of halite. (Marker bed 119)	1.0	1,156.0-1,157.0
Claystone, medium-gray (*N* 5); irregular in thickness	.7	1,157.0-1,157.7
Halite rock, moderate-reddish-orange (10*R* 6/5); contains about 10 percent polyhalite in blebs, and about 5 percent gray clay in layers	2.3	1,157.7-1,160.0
Claystone, medium-gray (*N* 5); contains about 30–50 percent halite and about 2 percent polyhalite near base	8.0	1,160.0-1,168.0
Halite rock, transparent, colorless; contains about 2 percent gray clay in blebs and 2 percent polyhalite in blebs; at 1,170 ft is moderate reddish orange (10*R* 6/6)	8.5	1,168.0-1,176.5
Polyhalite rock; contains discontinuous lenses of halite; grades into overlying unit. (Marker bed 120)	1.5	1,176.5-1,178.0
Halite rock, moderate-reddish-orange (10*R* 6/6)	.7	1,178.0-1,178.7
Halite rock; contains about 25 percent gray clay; top 0.2 ft is medium-gray (*N* 5) clay layer	.7	1,178.7-1,179.4
Halite rock, banded white and moderate-reddish-orange (10*R* 6/6); contains about 5 percent polyhalite in blebs and lenses	4.6	1,179.4-1,184.0
Halite rock; contains about 2 percent polyhalite in blebs and 2 percent gray clay in blebs	1.0	1,184.0-1,185.0
Halite rock, colorless; contains about 25–30 percent clay both reddish brown and gray in blebs; grades downward into underlying unit	6.0	1,185.0-1,191.0
Halite rock; contains about 10 percent polyhalite in blebs	2.7	1,191.0-1,193.7
Polyhalite rock; 0.1-ft-thick bed of gray clay at base. (Marker bed 121)	.9	1,193.7-1,194.6
Halite rock; contains about 2 percent gray clay and 2 percent polyhalite in blebs	7.4	1,194.6-1,202.0
Total partial thickness of Salado Formation	550.8	

Bottom of shaft.

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INTRODUCTION

The U.S. Geological Survey has selected and assembled sets of photographs that illustrate numerous types of geologic features in the United States. This catalog lists these special sets of photographs that are available for purchase and describes the features illustrated. One reduced photograph from each set is shown on the back pages of this catalog to assist the purchaser in his selection.

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Agricultural Stabilization and Conservation Service
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  mine tailings.......... Mich. 3; Pa. 2
  open pits.............. Ariz. 14; Ark. 4; Conn. 1; Ga. 1; N. Dak. 6; Pa. 2, 5; Utah 1
  pegmatite.............. Conn. 1
  slate.................. Pa. 5
  strip mines............ Ark. 4; Okla. 1, 3; W. Va. 1
Mogotes. *See* Karst, haystack hills.
Monocline................ Utah 7, 8
Moraines.
  See also Glaciers, moraines.
  ablation............... N. Dak. 2, 3; R.I. 1
  end.................... Alaska 12; Calif. 6, 8; Mont. 6; N. Dak. 2, 3; Pa. 5; Utah 2; Wyo. 1, 8
  faulted................ Calif. 13; Utah 2
  ice sheet.............. Mont. 6; N. Dak. 2, 3; Pa. 5; R.I. 1; Wis. 1
  interlobate............ Wis. 2, 3
  mountain glaciers...... Alaska 12; Calif. 6, 8, 11–15; Colo. 2; Maine 1; Mont. 2; Utah 2; Wash. 1; Wyo. 1, 8
  piedmont glaciers...... Alaska 11; Mont. 3
  two ages............... Calif. 11, 12; Utah 2; Wash. 1
Mountains.
  See also Cirques; Glaciers.
  complex structure...... Alaska 20; Colo. 2, 8; Tenn. 2
  fault-block............ Calif. 17, 23, 27; Mont. 19; N. Mex. 8; Tex. 2; Utah 2
  flat-lying rocks....... Mont. 2
    See also Plateaus.
  folded rocks........... Ark. 2, 3; Okla. 4; Pa. 6; Tex. 1; W. Va. 2, 3
  granitic rocks......... Calif. 6; Maine 1, 3; Mo. 1
  overthrust............. Mont. 1
  residual. *See* Inselbergs.
  synclinal.............. Okla. 3; Pa. 5
  volcanic. *See* Calderas; Cones; Volcanoes.
Mud cracks............... Calif. 22; Mont. 10
Mudflows................. Calif. 1, 5

Outwash plains........... N. Dak. 3; R.I. 1; Wis. 2; Wyo. 8

Paha..................... Iowa 2, 3
Patterned ground
  abandoned lake floor... Alaska 3
  active................. Alaska 1–6, 7, 9
  alluvial fans.......... Idaho 6
  ancient................ Idaho 2, 3, 6; N. Mex. 10, 11; Oreg. 6; Wash. 4
    See also Boulder fields.
  basalt................. Idaho 2, 3; N. Mex. 10, 11; Oreg. 6
  ice-wedge polygons..... Alaska 1, 2, 4, 5, 7, 9
  plowed fields.......... Alaska 9
  silt mounds............ Idaho 2, 6; N. Mex. 11; Oreg. 5
  stripes................ Alaska 1, 6; Idaho 2
Peat. *See* Swamps.
Pediments................ Ariz. 16, 16; Colo. 1, 3; N. Mex. 2, 9, 12; Utah 9
Permafrost. *See* Patterned ground, active.
Phacolith................ N.Y. 5
Piedmonts
  arid to semiarid....... Ariz. 15, 16; Calif. 17, 23, 33; Colo. 1, 3; N. Mex. 4; Utah 10, 11
  humid.................. Ark. 2; Ga. 1; Md. 1; Va. 4
Pingos................... Alaska 3, 6, 17
Plains
  coastal................ Ala. 1, 2; Alaska 1; N.J. 1; P.R. 5; S.C. 1
  desert................. Calif. 39; Nev. 2
  drift.................. Iowa 1, 3; N. Dak. 1, 2; Minn. 1; Mont. 5, 6, 11, 12
  lake. *See* Pleistocene lakes.
  sand. *See* Outwash plains.
  semiarid............... Tex. 3, 4
  volcanic............... Hawaii 4, 5; Idaho 5
Plateaus
  ash.................... Hawaii 3, 4
  basalt................. Hawaii 1; Utah 4, 6
    See also Seabland.
  dolomite............... Mo. 2; N.Y. 1
  limestone.............. Ariz. 4, 6, 13; Tex. 2, 5
  sandstone.............. Ariz. 8; Colo. 7; Utah 13, 14; W. Va. 1
Playas................... Calif. 23–26; Nev. 4
Pleistocene glacial features. *See* Arêtes; Eskers; Horns; Kames; Moraines; Outwash plains; Truncated spurs; Valleys, U-shaped.
Pleistocene lakes
  deltas................. Mich. 4; N.Y. 6; Pa. 4; Utah 2
  shorelines............. Calif. 32; Mich. 1; Nev. 1–3; N. Dak. 4–6; Ohio 1; Utah 2
  wave-cut cliffs........ Mich. 1; N. Dak. 6

Ring dikes............... N.H. 2
Rock glaciers............ Calif. 9, 10; Colo. 5, 8; Utah 3, 6
Rock types
  ash.................... Hawaii 3, 4
  basalt................. Alaska 8; Ariz. 4, 10, 12; Calif. 34; Conn. 1; Hawaii 1, 2, 5–7; Idaho 2, 4, 5, 7; Mich. 3, 4; Nev. 3; N. Mex. 2–5, 8, 10, 11; Utah 4; Wash. 5, 8, 10, 11
  bauxite................ Ark. 4
  chalk.................. Ala. 1

Rock types—Continued
  chert.................... Ark. 3; Okla. 2
  clay..................... Ala. 1; Ark. 4; Colo. 1; Md. 2; P.R. 6; S. Dak. 2
  coal..................... Okla. 1; Pa. 2; W. Va. 1
  colluvium................ Okla. 4
  dolomite................. Mo. 2, 3; N.Y. 1, 2; Va. 3
  eolian silt. *See* Loess.
  granitic................. Ariz. 5; Ark. 4; Calif. 6, 7, 9, 17-21, 33, 34; Colo. 5; Ga. 1; Maine 1, 3; Mo. 1; N.H. 1, 2; Tex. 6; Utah 10; Wyo. 1
  limestone................ Ariz. 4, 6, 13; Kans. 2; Ky. 1-4; Mont. 19; Pa. 1; P.R. 1-4, 6-8; S. Dak. 1; Tex. 1-3, 5, 6; Va. 1
  metasedimentary.......... Alaska 19; Calif. 20; Colo. 3; Md. 1; Mont. 1; N.Y. 4, 5; Tenn. 2; Vt. 1
  novaculite............... Ark. 2, 3; Okla. 2
  obsidian................. Calif. 3, 4, 8
  quartzite................ Pa. 5, 6; Va. 3, 5; W. Va. 3
  sandstone................ Ala. 1; Ariz. 1-3, 9, 13; Ark. 1, 2, 4; Colo. 3, 4, 7; Ky. 1, 3; Md. 2; Mich. 4; Mont. 3; N. Mex. 1; N.J. 1; N.Y. 4; Okla. 1, 3, 4; Pa. 1; S. Dak. 1; Tex. 1, 3, 4, 6; Utah 4, 7-9, 12-15; Va. 1, 2; W. Va. 1, 2; Wyo. 2, 5, 6, 9
  shale.................... Ariz. 1, 9, 13; Ark. 1, 2; Colo. 7; Kans. 2; Mont. 1, 3, 7, 8; N. Mex. 1, 4; N.Y. 1; Okla. 1-4; S. Dak. 1; Tex. 1; Utah 4, 7, 9, 11, 13, 15; Va. 5; W. Va. 1; Wyo. 2, 5-7, 9.
  silt..................... Alaska 1, 4-7, 9
  volcanic................. Calif. 5; Colo. 3, 8; Mont. 7; N. Mex. 4, 6; P.R. 8

Salt marsh. *See* Swamps, tidal; Playas.
Scabland
  basalt................... Idaho 4; Wash. 5, 8, 10, 11
  canyons.................. Wash. 5, 10
  dry falls................ Wash. 5
  giant ripple marks....... Wash. 8, 9, 11
  gravel bars.............. Idaho 4
Scarps, deflation.......... Colo. 6
Scree. *See* Talus.
Shoreline changes
  before and after......... Del. 1; La. 3; N.J. 2; N.C. 2
  during earthquake........ Mont. 17, 18, 20
  during hurricanes........ Fla. 3; N.C. 1
Shorelines.
  See also Beach ridges; Beaches.
  baymouth bars............ Calif. 36; R.I. 1
  headlands................ Oreg. 1; R.I. 1
  marine terraces. *See* Marine terraces.
  offshore bars............ Md. 2
  Pleistocene lakes. *See* Pleistocene lakes.
  prograding............... Fla. 1, La. 1; Mass. 1
  reverberation bay........ P.R. 5
  sea cliffs............... Alaska 21; Calif. 36, 37, 40, 41; Hawaii 2, 4; Md. 2; Oreg. 1; P.R. 5
    elevated............... Ala. 2; Calif. 38; Va. 7
  spits.................... Del 1; Mass. 1; N.J. 2; N.Y. 6; N.C. 1, 2
  stacks................... Calif. 37
  volcanic................. Hawaii 2, 4, 6, 10
Soil mounds. *See* Patterned ground.
Spring deposits............ N. Mex. 12
Stream captures............ Calif. 14; Va. 4
Stream channels
  abandoned................ Md. 1; Mo. 3; N.Y. 6
  ancient.................. Calif. 16
  braided.................. Alaska 14, 19, 22, 24; Ariz. 15; Calif. 28, 33, 34; Nebr. 4, 6
  buried by eolian sand.... Ariz. 3, 7; Nev. 4
  changes with time........ Kans. 1; Nebr. 1, 4; Va. 6
  drift-filled............. Conn. 1
  flood erosion............ Va. 2
  point bars............... Alaska 5; Iod. 2
  sand bars................ Nebr. 6; Utah 15
Stream diversions, by
  moraines................. Calif. 6
Stream piracy.............. Colo. 1, 4; Mo. 3; Utah 10, 11; Wyo. 3
  alluvial fans............ Calif. 28
Swamps..................... Maine 2; Mich. 5; N.Y. 4; N. Dak. 3; S.C. 1; Va. 7; Wis. 2
  coastal.................. Fla. 1; La. 3
  cypress.................. Fla. 2
  flood-plain.............. Ala. 1; La. 2; Miss. 1; Tenn. 1
  lakeshore................ Ind. 1
  mangrove................. Fla. 3; La. 6
  tidal.................... Fla. 2; La. 8, 9; Mass. 2; N.J. 2; Va. 6
Synclines.................. Ark. 1; Calif. 29; Okla. 2-4; Pa. 2, 5; Tex. 1; Va. 3, 5

Talus...................... Alaska 13; Ariz. 14; Calif. 3, 5, 8, 10; Mont. 1; Okla. 4; Utah 3; Wyo. 5
Tarns. *See* Lakes, rock basin.
Terraces
  deformed................. Mont. 13
  river.................... Alaska 2; Mont. 3, 4, 7; N. Mex. 4; S. Dak. 1; Utah 7, 10, 11; Va. 4; Wyo. 2, 4
Tidal marsh. *See* Swamps, tidal.
Tidal streams, meandering. *See* Swamps, tidal.
Topographic grain
  metamorphic rocks........ N.Y. 4, 5; Vt. 1
  shale.................... Ark. 2, 3
Travertine. *See* Spring deposits.
Trees, blown-down.......... Maine 1
Trimline of trees
  giant waves.............. Alaska 25, 26
  glacial.................. Alaska 15, 29
Truncated spurs............ Calif. 7, 15; Mont. 2; Wash. 3

Unconformities............. Ariz. 5; Colo. 4; N. Mex. 9, 10; N. Y. 4

Valleys
  hanging.............. Calif. 6, 7; Oreg. 4; Wash. 3
  U-shaped............. Alaska 13; Calif. 6, 7, 15; Maine 3; Mont. 2; N.H. 1; Oreg. 4; Utah 3; Wash. 2, 3
Volcanic necks........... Ariz. 2; N. Mex. 1
Volcanoes.
  See also Calderas; Cones; Craters; Domes, lava; Volcanic necks.
  before and after eruptions Hawaii 10
  dated flows........... Hawaii 5, 7–9
  extinct............... Calif. 2; Wash. 2, 7
  gullied slopes on ash.... Hawaii 3, 4
  rift zones............ Hawaii 7, 8; Idaho 5
  topographic differences related to climate..... Hawaii 1
Water gap.............. Pa. 6; W. Va. 3
Waterfalls............. Md. 1; N.Y. 2; Wash. 10
  dry.................. Calif. 6, 7; Wash. 5
Zanjones. *See* Joints, enlarged by solution.
Zigzag ridges........... Tex. 1

DETAILED DESCRIPTIONS OF SETS OF AERIAL PHOTOGRAPHS

Ala. 1. Ripley cuesta

County: Sumter.
Lat 32°37′ N.; long 88°08′ W.
Number of photographs: 3.
Photograph scale: 1:69,000.
Focal length: 5.2 in.
Date flown: Mar. 19, 1952.
Map reference: U.S. Geol. Survey Epes 15-min quadrangle, scale 1:62,500.
Geology reference: Monroe, W. H., and Hunt, J. L., 1958, Geology of the Epes quadrangle, Alabama: U.S. Geol. Survey Geol. Quad. Map GQ-113.

Features illustrated (*set nos. Ala. 1 A–C in southeast corner of photographs*).—The bedrock in this part of the Gulf Coastal Plain is of Late Cretaceous age. It is composed of gently southwest-dipping beds of chalk and some interbedded sand. In the northern two-thirds of photograph 1 C are gently rolling plains with large areas of bare white chalk—the southern edge of the Black Prairie Belt—bordered on the east by a wooded flood plain of the meandering Tombigbee River. Extending northwestward from the southeast corner of photograph 1 B, a steep northeast-facing scarp with a gentle back slope 4–5 miles long forms a belt of wooded hills. The hills are composed largely of sand (Ripley Formation) and are most conspicuous in the southeast quadrant of this photograph. The sandy beds are cut by closely spaced northwest-trending high-angle faults of small displacement. The faults control a network of closely spaced gullies and small valleys. Southwest of the cuesta (southwest quadrant of photograph 1 A) are densely wooded lowlands, the Flatwoods, underlain by Quaternary sand and gravel that overlies clay of Eocene age.

Ala. 2. Elevated marine bars on west side of Mobile Bay

County: Mobile.
Lat 30°25′ N.; long 88°12′ W.
Number of photographs: 3.
Photograph scale: 1:23,600.
Focal length: 6 in.
Date flown: Mar. 16, 1953.
Map reference: U.S. Geol. Survey Coden 7½-min quadrangle, scale 1:24,000.
Geology reference: Carlston, C. W., 1950, Pleistocene history of coastal Alabama: Geol. Soc. America Bull., v. 61, p. 1119–1130; geol. map (pl. 1), scale 1:250,000.

Features illustrated (*set nos. Ala. 2 A–C in northeast corner of photographs*).—Parallel ridges, about 30 feet above sea level, trend eastward just north of center of photograph 2 B and rise a few feet above a wooded swamp to north and south. To the west, the ridges abut against cultivated uplands as much as 90 feet in altitude. Carlston interprets these ridges as marine bars and the edge of the upland as a marine scarp, both of Pamlico age.

Alaska 1. Ice-wedge polygons near Point Barrow

Lat 71°14′ N.; long 156°45′W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 6 in.
Map reference: U.S. Geol. Survey Barrow sheet, scale 1:250,000.
Geology reference: Hopkins, D. M., Karlstrom, T. N. V., and others, 1955, Permafrost and ground water in Alaska: U.S. Geol. Survey Prof. Paper 264-F, p. 113–146, pl. 38.

Features illustrated (*set nos. Alaska 1 A–B in northeast corner of photographs*).—Thaw lakes and ice-wedge polygons are in stratified silt and sand on the Arctic coastal plain in the continuous permafrost zone. Thaw lakes, both frozen and unfrozen, are commonly elongated in a north-northwest direction and occupy the central parts of old lake basins whose outer parts show conspicuous patterns of low-center polygons (ridges separating pools of water). In higher areas outside the old lake basins, the polygons are smaller and less conspicuous and have high centers separated by troughs. On gentle slopes, polygonal patterns are replaced by stripes. Plate 38 in Professional Paper 264-F is an annotated copy of photograph 1 B.

Alaska 2. Polygonal ground on flood plain of Kogosukruk River

Lat 69°48′ N.; long 151°36′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 6 in.
Date flown: July 9, 1948.
Map reference: U.S. Geol. Survey Umiat sheet, scale 1:250,000.
Geology reference: Ray, R. G., 1960, Aerial photographs in geologic interpretation and mapping: U.S. Geol. Survey Prof. Paper 373, 230 p.

Features illustrated (*set nos. Alaska 2 A–B in southwest corner of photographs*).—Bands of ice-wedge polygons outline meander scars on the river flood plain. Serrated edge of oxbow lake and of terrace rims mark the location of thawed ice wedges. Permafrost is not present in the well-drained river terrace in the center of photograph 2 B between Kogosukruk River to the west and Colville River to the east. These two photographs are reproduced in figure 109 of Ray's paper.

Alaska 3. Pingo on arctic coastal plain

Lat 69°49′ N.; long 151°05′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 6 in.
Date flown: July 9, 1948.
Map reference: U.S. Geol. Survey Umiat sheet, scale 1:250,000.
Geology reference: Ray, R. G., 1960, Aerial photographs in geologic interpretation and mapping: U.S. Geol. Survey Prof. Paper 373, 230 p.

Features illustrated (*set nos. Alaska 3 A–B in southwest corner of photographs*).—Pingo is in northeast quadrant of photograph 3 A. Partly drained lake basins show abandoned shorelines and extensive areas of patterned ground. Modern lakes with serrated margins are partly covered by floating ice. These two photographs are reproduced as figure 110 in Ray's paper.

Alaska 4. Ice-wedge polygons and thaw lakes, Seward Peninsula

County: Second Judicial Division.
Lat 66°06′ N.; long 165°32′ W.
Number of photographs: 3.
Photograph scale: 1:40,000.
Focal length: 6 in.
Date flown: July 27, 1949.
Map reference: U.S. Geol. Survey Shishmaref sheet, scale 1:250,000.
Geology reference: Hopkins, D. M., Karlstrom, T. N. V., and others, 1955, Permafrost and ground water in Alaska: U.S. Geol. Survey Prof. Paper 264–F, p. 113–146, pl. 37.

Features illustrated (*set nos. Alaska 4 A–C in northwest corner of photographs*).—Coastal plain near Shishmaref Inlet (northwest corner of photograph 4 A) in the continuous-permafrost zone. Entire area is underlain by silt and peat. Permafrost present at a depth of 1½–3 feet everywhere except beneath rivers and lakes. Presence of permafrost is indicated by thaw lakes and basins of drained thaw lakes, beaded drainage, low- and high-center ice-wedge polygons. Scalloped margins of lakes and steep banks suggest active thawing. Plate 37 in Professional Paper 264–F is an annotated copy of photograph 4 B.

Alaska 5. Permafrost indicators, northern Seward Peninsula

County: Second Judicial Division.
Lat 65°20′ N.; long 164°24′ W.
Number of photographs: 3.
Photograph scale: 1:40,000.
Focal length: 6 in.
Date flown: June 20, 1950.
Map reference: U.S. Geol. Survey Bendeleben (B–5) quadrangle, scale 1:63,360.
Geology reference: Hopkins, D. M., Karlstrom, T. N. V., and others, 1955, Permafrost and ground water in Alaska: U.S. Geol. Survey Prof. Paper 264–F, p. 113–146, pl. 41.

Features illustrated (*set nos. Alaska 5 A–C in southeast corner of photographs*).—Northern three-quarters of photograph 5 B is underlain by 20–25 feet of peat and silt, southern quarter by fluvial and glaciofluvial sand and gravel mantled by only a few feet of peat and silt. Permafrost lies 1½–2 feet beneath the surface except beneath rivers and lakes. Permafrost is indicated by thaw lakes, modification of oxbow lakes by thawing, pingos, beaded drainage, low- and high-center ice-wedge polygons and vegetation stripes on slopes. Point bars are conspicuous along Kuzitrin River. Plate 41 in Professional Paper 264–F is an annotated copy of photograph 5 B.

Alaska 6. Flood-plain icing, northern Seward Peninsula

County: Second Judicial Division.
Lat 65°38′ N.; long 163°33′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Date flown: Oct. 2, 1946.
Map reference: U.S. Geol. Survey Bendeleben (C–4) quadrangle, scale 1:63,360.
Geology reference: Hopkins, D. M., Karlstrom, T. N. V., and others, 1955, Permafrost and ground water in Alaska: U.S. Geol Survey Prof. Paper 264–F, p. 113–146, pl. 43.

Features illustrated (*set nos. Alaska 6 A–B in northwest corner of photographs*).—White areas along streams in north half of photograph 6 A are new ice that had just begun to accumulate when photographs were taken. Ice on stream in southeast quadrant is perennial. (See Alaska 8.) Beaded drainage (thaw lakes) is conspicuous along streams in north half of photograph 6 B. Valley bottoms are underlain by silt, sand, and gravel as much as 10 feet thick, slopes by silt, as much as 20 feet thick, resting on basalt. Permafrost underlies the slopes at depth of 1½–3 feet and probably underlies flood plains at a depth of less than 10 feet. Area is 15 miles west of Imuruk Lake. Plate 43 *B* in Professional Paper 264–F is an annotated copy of photograph 6 A.

Alaska 7. Discontinuous permafrost, northern Seward Peninsula

County: Second Judicial Division.
Lat 65°35′ N.; long 163°20′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Date flown: Oct. 2, 1946.
Map reference: U.S. Geol. Survey Bendeleben (C–3) quadrangle, scale 1:63,360.
Geology reference: Hopkins, D. M., Karlstrom, T. N. V., and others, 1955, Permafrost and ground water in Alaska: U.S. Geol. Survey Prof. Paper 264–F, p. 113–146, pl. 31.

Features illustrated (*set nos. Alaska 7 A–B in northwest corner of photographs*).—Extensive permafrost is indicated by high-center ice-wedge polygons (northeast quadrant of photograph 7 A) and by the scalloped shore of Imuruk Lake (east edge of photograph 7 B). Presence of local unfrozen galleries and layers is shown by spring-fed streams that empty into closed basins. Except in the escarpment, the area is underlain by 5–20 feet of silt which rests on basaltic lava flows interbedded with thin layers of gravel; the escarpment is the front of a lava flow. Area is 35 miles south of Deering. Plate 31 in Professional Paper 264–F is an annotated copy of photograph 7 A.

Alaska 8. Perennial icing below hot springs, Seward Peninsula

County: Second Judicial Division.
Lat 65°35′ N.; long 163°30′ W.
Number of photographs: 1.
Date flown: Oct. 2, 1946.
Map reference: U.S. Geol. Survey Bendeleben sheet, scale 1:250,000.
Geology reference: Hopkins, D. M., Karlstrom, T. N. V., and others, 1955, Permafrost and ground water in Alaska: U.S. Geol. Survey Prof. Paper 264–F, p. 113–146, pl. 43C.

Features illustrated (*Oblique view eastward*).—Hot springs, marked by dense growth of tall willows are below center of photograph, near northwest base of volcanic cone. Winter flow of river, maintained by the springs, produces thick perennial ice (conspicuous white band). Growth of tall willows on flood plain downstream from the icing is shown also in Alaska 6. Imuruk Lake, in middle distance at left, is about half frozen. The dark area at right center is basaltic lava. Plate 43C in Professional Paper 264–F is an annotated copy of a part of this photograph.

Alaska 9. Microrelief due to thawing of ice-wedge polygons

Lat 64°52′ N.; long 147°50′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Date flown: Mar. 24, 1948.
Map reference: U.S. Geol. Survey Fairbanks (D–2) quadrangle, scale 1:63,360.
Geology reference: Hopkins, D. M., Karlstrom, T. N. V., and others, 1955, Permafrost and ground water in Alaska: U.S. Geol. Survey Prof. Paper 264–F, p. 113–146, pl. 42.

Features illustrated (*set nos. Alaska 9 A–B in northeast corner of photographs*).—Microrelief of shallow trenches, deep gullies, or closely spaced mounds formed in cleared fields when ground has thawed and ice wedges have melted down. View is of U.S. Department of Agriculture Experimental Farm near Fairbanks. Entire area is underlain by muck and silt that are permanently frozen and contain ice-wedge polygons. Polygons cannot be recognized where the forest is undisturbed. Plate 42 in Professional Paper 264–F is annotated copy of photograph 9 A.

Alaska 10. Stabilized sand dunes on plains northwest of Mount McKinley

Lat 63°39′ N.; long 152°42′ W.
Number of photographs: 2.
Photograph scale: 1:40,000.
Focal length: 6 in.
Date flown: Aug. 27, 1952.
Map reference: U.S. Geol. Survey Mount McKinley sheet, scale 1:250,000.
Geology reference: Reed, J. C., Jr., 1961, Geology of the Mount McKinley quadrangle, Alaska: U.S. Geol. Survey Bull. 1108–A, p. A1–A36; geol. map (pl. 1), scale 1:250,000. Ray, R. G., 1960, Aerial photographs in geologic interpretation and mapping: U.S. Geol. Survey Prof. Paper 373, 230 p.

Features illustrated (*set nos. Alaska 10 A–B in southwest corner of photographs*).—Linear and parabolic sand dunes, 50–150 feet high, that have a northeast trend. The dunes are now stabilized and support a growth of birch, aspen, and white spruce in contrast to the stunted black spruce and muskeg of the interdune areas. Figure 56 in Ray's report shows annotated copies of these photographs.

Alaska 11. Arcuate moraines northwest of Mount McKinley

County: Fourth Judicial Division.
Lat 63°12′ N.; long 151°49′ W.
Number of photographs: 2.
Photograph scale: 1:40,000.
Focal length: 6 in.
Date flown: Aug. 27, 1952.
Map reference: U.S. Geol. Survey Mount McKinley (A–4) quadrangle, scale 1:63,360.
Geology reference: Reed, J. C., Jr., 1961, Geology of the Mount McKinley quadrangle, Alaska: U.S. Geol. Survey Bull. 1108–A, p. A1–A36; geol. map (pl. 1), scale 1:250,000. Ray, R. G., 1960, Aerial photographs in geologic interpretation and mapping: U.S. Geol. Survey Prof. Paper 373, 230 p.

Features illustrated (*set nos. Alaska 11 A–B in southwest corner of photographs*).—Three moraines of two of Reed's older series on the plain northwest of Mount McKinley. Two of the arcuate moraines show almost unmodified topography that has innumerable small ponds; the third shows well-integrated drainage; all are of Pleistocene age. Figure 57 in Ray's report includes annotated copies of parts of these photographs.

Alaska 12. Stagnated terminus of Peters Glacier

Lat 63°15′ N.; long 151°00′ W.
Number of photographs: 2.
Photograph scale: 1:40,000.
Focal length: 6 in.
Date flown: July 21, 1952.
Map reference: U.S. Geol. Survey Mount McKinley sheet, scale 1:250,000.
Geology reference: Reed, J. C., Jr., 1961, Geology of the Mount McKinley quadrangle, Alaska: U.S. Geol. Survey Bull. 1108–A, p. A1–A36; geol. map (pl. 1), scale 1:250,000.

Features illustrated (*set nos. Alaska 12 A–B in southwest corner of photographs*).—Terminal lobe of Peters Glacier (ends at head of outwash stream, opposite fiducial mark on northeast edge of photograph 12 A); lobe consists of dead ice veneered with drift. A partly buried stream channel, its course marked by circular ponds, traverses the terminal lobe. Streams in tributary valleys have been blocked and diverted by at least two stages of lateral moraines. The terminus is surrounded by moraines of Recent age; the outermost, reaching a point about 2 miles from the present terminus, shows that the glacier formerly bifurcated.

Alaska 13. Ablation moraine, Muldrow Glacier

Lat 63°16′ N.; long 150°29′ W.
Number of photographs: 2.
Photograph scale: 1:47,700.
Focal length: 6 in.
Date flown: July 11, 1951.
Map reference: U.S. Geol. Survey Mount McKinley sheet, scale 1:250,000.

Features illustrated (*set nos. Alaska 13 A–B in southwest corner of photographs*).—Photographs show debris-mantled glacier in deep northeast-trending U-shaped valley about 12 miles above terminus. Highly contorted debris-covered bands alternate with bands of clear ice. Moraines are pockmarked with innumerable melting pits. Talus cones and avalanche chutes on steep valley walls. Large debris-covered tributary glaciers join south side of main ice stream to continue down glacier as debris-covered bands. Small glaciers are in headwaters of valleys draining northward from narrow bedrock divide (arêtes, horns) on north side of Muldrow Glacier (A. T. Fernald, written commun., 1964).

Alaska 14. Debris-covered terminus of Muldrow Glacier

Lat 63°24′ N.; long 150°33′ W.
Number of photographs: 3.
Photograph scale: 1:40,000.
Focal length: 6 in.
Date flown: Aug. 17, 1952.
Map reference: U.S. Geol. Survey Mount McKinley sheet, scale 1:250,000.

Features illustrated (*set nos. Alaska 14 A–C in southeast corner of photographs*).—These photographs taken in mid-August show melt-water ponds and streams on pitted ablation moraine. One stream is ice marginal; another follows a narrow flood plain within the area of debris-covered ice. A moraine parallels the north edge of the terminal lobe, and a valley train with conspicuous braided channels extends west from the terminus (A. T. Fernald, written commun., 1964). The bluff on the north side of the ice-marginal stream is loess, probably blown from the surface of the adjacent outwash plain.

Alaska 15. Rapid advance of Susitna Glacier, 1952–53

Lat 63°27′ N.; long 147°08′ W.
Number of photographs: 4.
Photograph scale: 1:40,000.
Focal length: 6 in.
Date flown: Sept. 9, 1949; July 3, 1954.
Map reference: U.S. Geol. Survey Healy B–1 and C–1 quadrangles, scale 1:63,360.
Geology reference: Post, A.S., 1960, The exceptional advances of the Muldrow, Black Rapids, and Susitna Glaciers: Jour. Geophys. Research, v. 65, no. 11, p. 3703–3712. Harrison, A. E., 1964, Ice surges on the Muldrow Glacier, Alaska: Jour. Glaciology, v. 5, no. 39, p. 365–368.

Features illustrated.—The 1949 photographs (*set nos. Alaska 15 C–D in northeast corner*) show collapsed terminal segment of glacier ending in a broad outwash plain. The surface is debris covered and has many conspicuous circular ponds. Patches of bare ice appear about 4 miles back from the terminus. There is a conspicuous trimline on the valley sides. The 1954 photographs (*set nos. Alaska 15 A–B in southeast corner*) show that the surface features in the active (bare) part of the glacier have been displaced down valley more than 2 miles. Part of the stagnant terminal area was not overwhelmed, and some of the circular ponds showed little change during this interval. The surge probably occurred in 1952 or 1953. The surface of the upper part of the glacier, east of area shown in these photographs, is covered by a similar "before and after" set. (See Alaska 16.)

Alaska 16. Lowering of surface of Susitna Glacier, 1952–53

Lat 63°28′ N.; long 146°40′ W.
Number of photographs: 4.
Photograph scale: 1:40,000.
Focal length: 6 in.
Date flown: Aug. 29, 1949; July 3, 1954.
Map reference: U.S. Geol. Survey Mount Hayes B–6 and C–6 quadrangles, scale 1:63,360.
Geology reference: Post, A. S., 1960, The exceptional advances of the Muldrow, Black Rapids, and Susitna Glaciers: Jour. Geophys. Research, v. 65, no. 11, p. 3703–3712.

Features illustrated.—The 1949 photographs (*set nos. Alaska 16 A–B in northeast corner*) show snow-covered smooth surface of upper part of Susitna Glacier. The area shown is about 15 miles from terminus and includes several ice streams and many nunataks. The main trunk of Susitna Glacier leaves the area shown in northwest quadrant of photograph 16 A. The 1954 photographs (*set nos. Alaska 16 C–D in southeast corner; photograph 16 C covers most of area shown in photograph 16 A*) show that the surface of the glacier has been lowered about 200 feet and is intensely crevassed. This lowering probably occurred in 1952 or 1953 in association with the surge of the ice near the terminus. (See Alaska 15.)

Alaska 17. Yukon-Tanana pingos

Lat 63°29′ N.; long 141°57′ W.
Number of photographs: 2.
Photograph scale: 1:43,000.
Focal length: 6 in.
Date flown: Sept. 14, 1948.
Map reference: U.S. Geol. Survey Tanacross B–2, B–3, C–2, and C–3 quadrangles, scale 1:63,360.
Geology reference: Holmes, G. W., Hopkins, D. M., and Foster, H. L., 1967, Distribution and age of pingos of interior Alaska: Natl. Acad. Sci. Internat. Conf. Permafrost, Proc., Purdue Univ., November 1963.

Features illustrated (set nos. Alaska 17 A–B in southeast corner of photographs).—These pingos in the Yukon-Tanana upland are on the lower valley wall and valley floor of tributaries to Dennison Fork. The mounds are roughly circular in plan. Some are undisturbed and some partly slumped; one has a round pond in the center. These pingos are shown in figure 7 of the paper referred to above.

Alaska 18. Glaciers within and adjacent to Katmai Caldera

Lat 58°16′ N.; long 154°58′ W.
Number of photographs: 5.
Photograph scale: 1:42,400.
Focal length: 6 in.
Date flown: Aug. 23, 1951.
Map reference: U.S. Geol. Survey Mount Katmai A–3, A–4, B–3, and B–4 quadrangles, scale 1:63,360.
Geology reference: Muller, E. H., and Coulter, H. W., 1957a, Incipient glacier development within Katmai caldera, Alaska: Jour. Glaciology, v. 3, no. 21, p. 13–17. 1957b, The Knife Creek glaciers of Katmai National Monument, Alaska: Jour. Glaciology, v. 3, no. 22, p. 116–122.

Features illustrated (set nos. Alaska 18 A–E in northwest corner of photographs).—Crater Lake in Katmai Caldera (east half of photograph 18 B), formed during the 1912 eruption of Mount Katmai, contains small post-1912 glaciers on the north and south rims. The Knife Creek glaciers (west of lake) appear to be static. The terminus of Fourth Glacier (southwest corner of photograph 18 A) has not moved since 1912, and upper part of glacier near caldera rim has thinned. The glacier was beheaded by the eruption and lost its source area. The ice tongues on the south slope of Mount Katmai (photograph 18 D) end in small valleys that descend steeply to the alluvial plain of Katmai River.

Alaska 19. Outwash plain of Tustumena Glacier

Lat 60°04′ N.; long 150°35′ W.
Number of photographs: 3.
Photograph scale: 1:39,000.
Date flown: July 17, 1950.
Map reference: U.S. Geol. Survey Kenai (A–2) quadrangle, scale 1:63,360.
Geology reference: Karlstrom, T. N. V., 1964, Quaternary geology of the Kenai lowland and glacial history of the Cook Inlet region, Alaska: U.S. Geol. Survey Prof. Paper 443, 69 p.; see fig. 9.

Features illustrated (set nos. Alaska 19 A–C in southeast corner of photographs).—Bare surface of the glacier ice has complex patterns of crevasses. The glacier diverts a small stream across a former interfluve. A compound moraine can be seen just beyond the glacier terminus, and a third moraine closely parallels a part of the shore of Tustumena Lake. The braided channels of the outwash plain are conspicuous. The bedrock is graywacke, argillite, and similar rocks of Cretaceous age and is highly folded and fractured. A small rock-basin lake lies about a mile north of the glacier (southeast quadrant of photograph 19 C).

Alaska 20. Worthington Glacier northeast of Valdez

Lat 61°10′ N.; long 145°45′ W.
Number of photographs: 4.
Photograph scale: 1:40,000.
Focal length: 6 in.
Date flown: Aug. 12, 1950.
Map reference: U.S. Geol. Survey Valdez (A–5) quadrangle, scale 1:63,360. American Geographical Society, 1960, Worthington Glacier, Alaska, sheet 5 of nine glacier maps, northwestern North America: Am. Geog. Soc., Spec. Pub. 34, scale, 1:10,000.
Geology reference: Coulter, H. W., and Coulter, E. B., 1961, Geology of the Valdez (A–5) quadrangle, Alaska: U.S. Geol. Survey Geol. Quad. Map GQ–142.

Features illustrated (set nos. Alaska 20 A–D in southeast corner of photographs).—Worthington Glacier, approximately 4 miles long, descends eastward from a broad névé field to a bifurcated terminus (near center of photograph 20 B). Morainal deposits extend about 1,500 feet beyond the terminus. The largest spruce tree on the outer loop of this moraine has 65 annual rings. The small cirque glaciers on the surrounding mountains and the large glacier about 3 miles to the north (southwest quadrant of photograph 20 D) show conspicuous bare moraines apparently formed during the current retreat. Arêtes and horns are conspicuous. Bedrock is phyllitic graywacke that shows a conspicuous east-west grain.

Alaska 21. Marine terraces on Middleton Island

County: Third Judicial Division.
Lat 59°26′ N.; long 146°20′ W.
Number of photographs: 2.
Photograph scale: 1:40,000.
Focal length: 6 in.
Date flown: Sept. 14, 1955.
Map reference: U.S. Geol. Survey Middleton Island (B–7) quadrangle, scale 1:63,360.

Geology reference: Miller, D. J., 1953, Late Cenozoic marine glacial sediments and marine terraces of Middleton Island, Alaska: Jour. Geology, v. 61, no. 1, p. 17–40; geol. map (fig. 2), scale 1:40,000.

Features illustrated (set nos. Alaska 21 A–B in northwest corner of photographs).—Five terrace levels 10–105 feet above present sea level are clearly shown. Intervening raised sea cliffs are precipitous. The bedrock is a Pliocene or Pleistocene sequence of slightly to moderately indurated marine clastic sediments that dip about 25° NW.

Alaska 22. Delta and grooved drift near stagnant margin of Malaspina Glacier

Lat 59°58′ N.; long 141°15′ W.
Number of photographs: 2.
Photograph scale: 1:40,000.
Focal length: 6 in.
Date flown: June 30, 1948.
Map reference: U.S. Geol. Survey Icy Bay sheet, scale 1:250,000.
Geology reference: Plafker, George, and Miller, D. J., 1958, Glacial features and surficial deposits of the Malaspina district, Alaska: U.S. Geol. Survey Misc. Geol. Inv. Map I–271, scale 1:25,000.

Features illustrated (set nos. Alaska 22 A–B in northwest corner of photographs).—A subglacial stream (Yahtse River) emerges from Malaspina Glacier (near center of photograph 22 A) and flows westward to empty into Icy Bay where it has built a small delta. North and south of the river are ridges of drift that rise above the outwash plain. Southeast-trending grooves across these ridges show that they have been overridden by southeastward-moving ice—probably an advance of the Guyot Glacier between 1700 and 1791 A.D. The south-trending band of braided channels and the scattered trees and shrubs along the vegetation-covered west margin of the glacier (near southwest edge of photograph 22 A) is the abandoned channel of Yahtse River. The river used this channel when Icy Bay was blocked by Guyot Glacier. Stagnant crevassed ice and ablation-moraine-covered pitted ice are shown in east half of photograph 22 A. Near southwest edge of exposure, the ablation moraine is partly covered by vegetation.

Alaska 23. Deformed moraines of Malaspina Glacier

Lat 60°06′ N.; long 140°35′ W.
Number of photographs: 2.
Photograph scale: 1:40,000.
Focal length: 6 in.
Date flown: June 30, 1948.
Map reference: U.S. Geol. Survey Mount St. Elias sheet, scale 1:250,000.
Geology reference: Plafker, George, and Miller, D. J., 1958, Glacial features and surficial deposits of the Malaspina district, Alaska: U.S. Geol. Survey Misc. Geol. Inv. Map I–271, scale 1:125,000. Sharp, R. P., 1958, Malaspina Glacier, Alaska: Geol. Soc. America Bull., v. 69, p. 617–646.

Features illustrated (set nos. Alaska 23 A–B in northwest corner of photographs).—Moraine bands on the surface of Malaspina Glacier just west of its junction with Seward Glacier (east corner of photograph 23 A) which supplies more than two-thirds of the ice in this great piedmont glacier. Oily Lake and associated ponds (see Map I–271) lie along the contact of the ice and the south slope of Samovar Hills.

Alaska 24. Outwash apron and forested margin of Malaspina Glacier

Lat 59°43′ N.; long 140°24′ W.
Number of photographs: 2.
Photograph scale: 1:40,000.
Focal length: 6 in.
Date flown: June 20, 1948.
Map reference: U.S. Geol. Survey Yakutat sheet, scale 1:250,000.
Geology reference: Plafker, George, and Miller, D. J., 1958, Glacial features and surficial deposits of the Malaspina district, Alaska: U.S. Geol. Survey Misc. Geol. Inv. Map I–271, scale 1:25,000.

Features illustrated (set nos. Alaska 24 A–B in northwest corner of photographs).—A banded surface of bare glacier ice (northwest part of photograph 24 B, not in stereo) is separated from an outwash apron fronting the Gulf of Alaska by a belt of forest-covered glacier ice nearly a mile wide. Active outwash streams have conspicuous braided channels and are bare. Recently abandoned outwash aprons, between active streams, are largely brush covered. Ancient beach ridges behind the present-day shore support trees and shrubs. Stereoscopic area is adjacent to Alder Stream west of Point Manby.

Alaska 25. Moraines and floating terminus of Lituya Glacier

Lat 58°42′ N.; long 137°32′ W.
Number of photographs: 3.
Photograph scale: 1:25,000.
Focal length: 6 in.
Date flown: Aug. 11, 1959.
Map reference: U.S. Geol. Survey Mount Fairweather sheet, scale 1:250,000.
Geology reference: Miller, D. J., 1960, Giant waves in Lituya Bay, Alaska: U.S. Geol. Survey Prof. Paper 354–C, p. 51–86.

Features illustrated (set nos. Alaska 25 A–C in northeast corner of photographs).—Lituya Glacier, which has prominent medial and lateral moraines, flows down the southwest slope of the Fairweather Range and then turns southeast into Lituya Bay. The terminal part of the ice is floating—a tidal glacier—and has a crevasse pattern different from that upstream. Material has slid down the steep valley walls and out onto the ice. Perhaps the discontinuous medial moraine on the inside of the bend in the glacier originated from such a landslide. On the steep walls of the bay just beyond the glacier terminus is the trimline or upper limit of destruction of forest by a giant wave caused by a landslide (east of glacier terminus) during the 1958 earthquake.

Alaska 26. Crillon Glacier: Calving terminus of North Crillon Glacier

Lat 58°40′ N.; long 137°28′ W.
Number of photographs: 3.
Photograph scale: 1:25,000.
Focal length: 6 in.
Date flown: Aug. 11, 1959.
Map reference: U.S. Geol. Survey Mount Fairweather sheet, scale 1:250,000.
Geology reference: Miller, D. J., 1960, Giant waves in Lituya Bay, Alaska: U.S. Geol. Survey Prof. Paper 354–C, p. 51–86.

Features illustrated (set nos. Alaska 26 A–C in northeast corner of photographs).—A stream emerging from beneath the glacier is building a delta into Lituya Bay, a fiord. A part of the terminus is grounded on the delta. The remainder, where the ice is floating, forms a reentrant, and the glacier is calving. Fractures in the ice curve around the reentrant. Adjacent to the delta, the ice is largely concealed beneath an ablation moraine. Beyond the terminus can be seen the trimline or upper limit of destruction of trees by a giant wave caused by a landslide into the bay during the 1958 earthquake. (Sets Alaska 26–28—Crillon Glacier—form a continuous series.)

Alaska 27. Crillon Glacier: Moraines at junction of North and South Crillon Glaciers

Lat 58°38′ N.; long 137°27′ W.
Number of photographs: 2.
Photograph scale: 1:25,000.
Focal length: 6 in.
Date flown: Aug. 11, 1959.
Map reference: U.S. Geol. Survey Mount Fairweather sheet, scale 1:250,000.
Geology reference: Miller, D. J., 1960, Giant waves in Lituya Bay, Alaska: U.S. Geol. Survey Prof. Paper 354–C, p. 51–86.

Features illustrated (set nos. Alaska 27 A–B in northeast corner of photographs).—South Crillon Glacier (southeast half of photograph 27 A) flows west down the southwest slope of Fairweather Range. At the foot of the slope it divides; part flows southeast to Crillon Lake and part northwest to Lituya Bay. The northwest fork is joined by North Crillon Glacier; below the junction a medial moraine has formed. The lower part of the combined glacier is largely covered with debris (ablation moraine). (Sets Alaska 26–28—Crillon Glacier—form a continuous series.)

Alaska 28. Crillon Glacier: Fairweather fault and terminus of South Crillon Glacier

Lat 58°36′ N.; long 137°25′ W.
Number of photographs: 3.
Photograph scale: 1:25,000.
Focal length: 6 in.
Date flown: Aug. 11, 1959.
Map reference: U.S. Geol. Survey Mount Fairweather sheet, scale 1:250,000.
Geology reference: Miller, D. J., 1960, Giant waves in Lituya Bay, Alaska: U.S. Geol. Survey Prof. Paper 354–C, p. 51–86.

Features illustrated (set nos. Alaska 28 A–C in northeast corner of photographs).—Terminus of South Crillon Glacier in ice-damned Crillon Lake. Northeast of the lake the trace of the Fairweather fault is clearly visible except where the fault crosses a small alluvial fan. This fresh scarp records fault movement on July 9, 1958, about a year before this photograph was taken. Two small glaciers lie northeast of the lake. The western one is completely covered by ablation moraine and appears to be cut off from its former ice source. The eastern one is deeply crevassed and is fed by an icefall. (Sets Alaska 26–28—Crillon Glacier—form a continous series.)

Alaska 29. Partly stagnant terminus of La Perouse Glacier

County: First Judicial Division.
Lat 58°28′ N.; long 137°09′ W.
Number of photographs: 3.
Photograph scale: 1:25,000.
Focal length: 6 in.
Date flown: Aug. 11, 1959.
Map reference: U.S Geol. Survey Mount Fairweather sheet, scale 1:250,000.

Features illustrated (set nos. Alaska 29 A–C in northeast corner of photographs).—A narrow ice tongue descends the southwest slope of Fairweather Range (north quadrant of photograph 29 B) and spreads out as a small piedmont glacier having four or five small tongues. Parts of the tongues are covered with ablation moraine; the southeasternmost one is forested. The tongues are surrounded by wooded morainal ridges that have a conspicuous trimline and that dam small lakes. (H. W. Coulter, written commun., 1964.)

Alaska 30. Nunataks in icefield near Castle Mountain

Lat 56°57′ N.; long 132°22′ W.
Number of photographs: 2.
Photograph scale: 1:40,000.
Focal length: 6 in.
Date flown: July 5, 1948.
Map reference: U.S. Geol. Survey Petersburg sheet, scale 1:250,000.

Features illustrated (set nos. Alaska 30 A–B in southeast corner of photographs).—Nunataks are steep-sided peaks rising as much as 1,000 feet above the surface of the glacier, which is here flat to gently sloping. The ice is largely snow covered except on the lower slopes of the peaks where belts of crevasses are conspicuous. Geographic coordinates given above are approximate.

Ariz. 1. Merrick Butte and The Mittens, Monument Valley

County: Navajo.
Lat 36°59′ N.; long 110°05′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 6 in.
Date flown: Sept. 15, 1951.
Map reference: U.S. Geol. Survey Agathla Peak 15-min quadrangle, scale 1:62,500.
Geology reference: Witkind, I. J., and Thaden, R. E., 1963, Geology and uranium-vanadium deposits of the Monument Valley area, Apache and Navajo Counties, Arizona: U.S. Geol. Survey Bull. 1103, 171 p.; geol. map (pl. 1), scale 1:62,500.

Features illustrated (set nos. Ariz. 1 A–B in southeast corner of photographs).—These three "monuments"—small buttes more than 1,000 feet high—are the erosional remnants of a once-continuous cover of sedimentary rocks. The most resistant unit in the stratigraphic sequence is a light-gray conglomeratic sandstone, the Shinarump Member of the Chinle Formation; a small cap of the Shinarump is still preserved on the flat top of Merrick Butte (southwest quadrant of photograph 1 A). The Shinarump is underlain by soft easily eroded reddish-brown shaly siltstone, the Moenkopi Formation, which forms slopes. The vertical walls of the monuments are the light-brown De Chelly Sandstone Member of the Cutler Formation. The broad flaring aprons around the bases of the monuments are underlain by the easily eroded Organ Rock Tongue of the Cutler Formation.

Ariz. 2. Agathla Peak, a volcanic neck

County: Navajo.
Lat 36°50′ N.; long 110°14′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 6 in.
Date flown: Sept. 15, 1951.
Map reference: U.S. Geol. Survey Agathla Peak 15-min quadrangle, scale 1:62,500.
Geology reference: Witkind, I. J., and Thaden, R. E., 1963, Geology and uranium-vanadium deposits of the Monument Valley area, Apache and Navajo Counties, Arizona: U.S. Geol. Survey Bull. 1103, 171 p.; geol. map (pl. 1), scale 1:62,500.

Features illustrated (set nos. Ariz. 2 A–B in southeast corner of photographs).—This volcanic plug, about 1,400 feet high, is the igneous rock that once filled the conduit (throat) of a volcano when the land surface was far above the present one. The sedimentary rocks that originally enclosed the plug were weaker than the igneous rock and have been eroded away. The desert surrounding Agathla Peak is underlain by lenticular sandstone and conglomerate of the Monitor Butte Member of the Chinle Formation. Owl Rock, a 500-foot needle of siltstone and sandstone with a small cap of Wingate Sandstone, rises from the surface of a prominent cuesta near west edge of the photographs.

Ariz. 3. Dunes at base of Comb Ridge

County: Navajo.
Lat 36°51′ N.; long 110°01′ W.
Number of photographs: 3.
Photograph scale: 1:20,000.
Focal length: 6 in.
Date flown: Sept. 16, 1951.
Map reference: U.S. Geol. Survey Agathla Peak and Dinnehotso 15-min quadrangles, scale 1:62,500.
Geology reference: Witkind, I. J., and Thaden, R. E., 1963, Geology and uranium-vanadium deposits of the Monument Valley area, Apache and Navajo Counties, Arizona: U.S. Geol. Survey Bull. 1103, 171 p.; geol. map (pl. 1), scale 1:62,500.

Features illustrated (set nos. Ariz. 3 A–C in southeast corner of photographs).—Comb Ridge is a north-facing cliff, capped by Navajo Sandstone, that dips southeast off the Agathla anticline. To the north, Little Capitan Valley separates the ridge from a dip slope on the De Chelly Sandstone Member of the Cutler Formation. The valley is floored with eolian sand that forms transverse dunes and barchans and buries the mouths of washes that drain into the valley from the north, such as the wash in Double Arch Canyon (northwest quadrant of photograph 3 C). Small ephemeral lakes occur among the dunes. South of Comb Ridge the Navajo Sandstone is concealed beneath a sheet of eolian sand which forms longitudinal dune ridges.

Ariz. 4. Lava flows and cones at Vulcans Throne, Grand Canyon

County: Coconino and Mohave.
Lat 36°13′ N.; long 113°07′ W.
Number of photographs: 3.
Photograph scale: 1:63,360.
Focal length: 6 in.
Date flown: June 2, 1953.
Map reference: U.S. Geol. Survey Grand Canyon sheet, scale 1:250,000.
Geology reference: Gregory, H. E., 1932, Colorado Plateau region: Internat. Geol. Cong., 16th, Washington, 1932, Guidebook 18, Excursions C–1 and C–2, 38 p.

Features illustrated (set nos. Ariz. 4 A–C in southeast corner of photographs).—The Aubrey Cliffs, capped by flat-lying Kaibab Limestone (Permian), border the east side of Prospect Valley (southeast quadrant of photograph 4 B), south of the Colorado River. Fault scarps cut alluvial fans along the west base of cliffs. Lava flows, chiefly north of the river on the edge of Tuweep Valley, spilled down the sides of the inner gorge to the river. Cinder cones both north and south of the river are alined with a fault scarp to the south.

Ariz. 5. Grand Canyon at Bright Angel Creek

County: Coconino.
Lat 36°06′ N.; long 112°06′ W.
Number of photographs: 3.
Photograph scale: 1:36,000.
Focal length: 6 in.
Date flown: Aug. 19, 1960.
Map reference: U.S. Geol. Survey Bright Angel 15-min quadrangle, scale 1:62,500.
Geology reference: Maxson, J. H., 1961, Geologic map of the Bright Angel quadrangle, Grand Canyon National Park, Arizona: Grand Canyon Nat. History Assoc. Text on back of map.

Features illustrated (set nos. Ariz. 5 A–C in northeast corner of photographs).—The Granite Gorge, the Tonto Plateau, and the lower part of the walls of the main canyon are shown in this triplet at whose center is the suspension bridge across the Colorado River just above the mouth of Bright Angel Creek. In the Granite Gorge near the southeast edge of photograph 5 B, the Zoroaster Granite can be seen adjacent to the Brahma Schist. In the west quadrant of the same photograph, the mesa on the north side of the gorge is capped by Tapeats Sandstone. To the north, Cheops Pyramid, capped by Redwall Limestone, is surrounded by gentle slopes underlain by Algonkian sedimentary rocks that rest unconformably on the Brahma Schist and are themselves overlain unconformably by the Tapeats Sandstone or Bright Angel Formation of Cambrian age.

Ariz. 6. Mouth of the Little Colorado River

County: Coconino.
Lat 36°10′ N.; long 111°47′ W.
Number of photographs: 3.
Photograph scale: 1:60,000.
Focal length: 6 in.
Date flown: Oct. 11, 1955.
Map reference: U.S. Geol. Survey Grand Canyon National Park, east half, scale 1:48,000.
Geology reference: Gregory, H. E., 1932, Colorado Plateau region: Internat. Geol. Cong., 16th, Washington, 1933, Guidebook 18, Excursions C–1 and C–2, 38 p.; geol. map (fig. 1), scale 1:734.000.

Features illustrated (set nos. Ariz. 6 A–C in northeast corner of photographs).—The narrow and steep-sided canyon of the Little Colorado River (southeast quadrant of photograph 6 B) is incised below a broad plateau of flat-lying Kaibab Limestone. Along the Colorado River north of the junction, the Redwall Limestone forms a narrow inner gorge close to the river. A high-angle fault that parallels the Colorado about 2 miles to the west separates Paleozoic rocks (Kaibab Limestone to Tonto group) on the east from Precambrian sedimentary rocks (Grand Canyon Series) on the west.

Ariz. 7. Dunes on Kaibito Plateau north of Moenkopi

County: Coconino.
Lat 36°15′ N.; long 111°11′ W.
Number of photographs: 3.
Photograph scale: 1:20,000.
Focal length: 6 in.
Date flown: Oct. 9, 1952.
Map reference: U.S. Geol. Survey Marble Canyon sheet, scale 1:250,000.
Geology reference: Hack, J. T., 1941, Dunes of the western Navajo Country: Geog. Rev., v. 31, no. 2, p. 240–263; see fig. 2. Gregory, H. E., 1917, Geology of the Navajo Country: U.S. Geol. Survey Prof. Paper 93, 161 p.; see p. 136–138.

Features illustrated (set nos. Ariz. 7 A–C in southeast corner of photographs).—Thin mantle of dune sand on Kaibito Plateau north of Moenkopi. Navajo Sandstone of Jurassic and Triassic(?) age is exposed in many places. Dune forms include active and fixed parabolic dunes, transverse dunes, and barchans. A stream valley partly filled with dune sand is visible near the east margin of photographs 7 B and 7 C.

Ariz. 8. Dunes on Moenkopi Plateau

County: Coconino.
Lat 35°52′ N.; long 111°10′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 6 in.
Date flown: Oct. 10, 1952.
Map reference: U.S. Geol. Survey Flagstaff sheet, scale 1:250,000.
Geology reference: Hack, J. T., 1941, Dunes of the western Navajo Country: Geog. Rev., v. 31, no. 2, p. 240–263; see fig. 18.

Features illustrated (set nos. Ariz. 8 A–B in southeast corner of photographs).—Longitudinal and parabolic dunes near the edge of the plateau. Source of the sand is the sandstone at the plateau edge which has been eroded by running water and by sapping. The escarpment overlooks the edge of the Painted Desert in the southwest corner of photograph 8 A.

Ariz. 9. Sand dunes and floodwater farming, Jeddito Valley

County: Navajo.
Lat 35°43′ N.; long 110°17′ W.
Number of photographs: 3.
Photograph scale: 1:54,000.
Focal length: 6 in.
Date flown: Feb. 20, 1954.
Map reference: U.S. Geol. Survey Flagstaff sheet, scale 1:250,000.
Geology reference: Hack, J. T., 1941, Dunes of the western Navajo Country: Geog. Rev., v. 31, no. 2, p. 240–263; see fig. 21. Hack, J. T., 1942, The changing physical environment of the Hopi Indians of Arizona: Harvard Univ., Peabody Mus. Papers, v. 35, no. 1, 85 p.

Features illustrated (set nos. Ariz. 9 A–C in northeast corner of photographs).—Antelope Mesa (northeast quadrant of photograph 9 B) is underlain by Mesaverde Sandstone and covered by a veneer of dune sand. Southwest winds predominate and parabolic dunes, open in that direction, cover much of the mesa. These dunes have vegetation on them and many are inactive. Active parabolic dunes occur on the mesa just south of the head of Tallahogan Wash (the light-colored area just to east of center of photograph 9 B). The source of this sand is the alluvium in the valley to the northwest. Peach orchards and irrigated gardens are on the south slope of Tallahogan Wash. Jeddito Valley, south of Antelope Mesa, is eroded in Mancos Shale but contains a thick fill of sandy alluvium. Many cornfields are at the ends of southward-draining arroyos and are watered by floods that spread over them during occasional summer rains.

Ariz. 10. Sunset Crater

County: Coconino.
Lat 35°22′ N.; long 111°30′ W.
Number of photographs: 2.
Photograph scale: 1:16,000.
Focal length: 8.25 in.
Date flown: May 28, 1960.
Map reference: U.S. Geol. Survey Flagstaff sheet, scale 1:250,000.
Geology reference: Cosner, O. J., 1962, Ground water in the Wupatki and Sunset Crater National Monuments, Coconino County, Arizona: U.S. Geol. Survey Water-Supply Paper 1475–J, p. 357–374; geol. map (pl. 20), scale 1:63,360.

Features illustrated (set nos. Ariz. 10 A–B in southeast corner of photographs).—Cinder cone of late Pleistocene or Recent age surrounded by a plain largely mantled by cinders but including some outcrops of basalt. Northwest of the cone is the head of the Bonito lava flow which issued from near the base of the cone. The rim of the cone is light colored because of oxidation by late fumarole activity.

Ariz. 11. Longitudinal, parabolic, and transverse dunes on Garces Mesa

County: Coconino.
Lat 35°39′ N.; long 110°55′ W.
Number of photographs: 3.
Photograph scale: 1:54,000.
Focal length: 6 in.
Date flown: Feb. 19, 1954.
Map reference: U.S. Geol. Survey Flagstaff sheet, scale 1:250,000.
Geology reference: Hack, J. T., 1941, Dunes of the western Navajo Country: Geog. Rev., v. 31, no. 2, p. 240–263.

Features illustrated (set nos. Ariz. 11 A–C in northeast corner of photographs).—A broad plateau rises 100–200 feet above the adjacent wide valleys traversed by meandering arroyos. Most of the area is covered by a thin sheet of dune sand whose source is partly alluvium transported in the arroyos and partly the erosion and sapping of the sandstone that caps the mesa edges. The Sand Springs dune area shown in figure 16 of Hack's paper is the plateau whose edges are partly buried by climbing dunes in the southeast quadrant of photograph 11 C. Hack believes that the transverse dunes form where the greatest amount of sand is in motion, for example just to the lee (northeast) of the climbing dunes. Parabolic dunes form where there is somewhat less actively moving sand, and longitudinal dunes form where the rate of sand transport is least. The transverse dunes have no vegetation except in the troughs between them. The parabolic and longitudinal dunes have a sparse vegetative cover. Little sand is in motion in the darker gray areas between the dunes.

Ariz. 12. Diatremes near Bidahochi

County: Navajo.
Lat 35°29′ N.; long 110°05′ W.
Number of photographs: 3.
Photograph scale: 1:54,000.
Focal length: 6 in.
Date flown: Feb. 24, 1954.
Map reference: U.S. Geol. Survey Flagstaff sheet, scale 1:250,000.
Geology reference: Hack, J. T., 1942, Sedimentation and volcanism in the Hopi Buttes, Arizona: Geol. Soc. America Bull., v. 53, p. 335–372; see fig. 8.

Features illustrated (set nos. Ariz. 12 A–C in northeast corner of photographs).—Photograph 12 B shows many buttes and mesas. In general, the darker colored ones are basalt and the lighter colored ones are diatremes, such as the light-colored butte in the northwest corner of this exposure. A second diatreme, Hack's 2, is at the west end of a small basalt mesa (about 1 in. south-southwest of center of north edge of same exposure). This diatreme is about 300 feet in diameter. Its walls flare widely and the beds dip inward. The filling is mostly well stratified basalt tuff. Hack's diatreme 4 is at the south end of a basalt mesa about due east of the center of photograph 12 B.

Ariz. 13. Colorado Plateau and Canyon Diablo near Meteor Crater

County: Coconino.
Lat 35°04′ N.; long 111°02′ W.
Number of photographs: 2.
Photograph scale: 1:40,000.
Focal length: 6 in.
Date flown: Sept. 20, 1948.
Map reference: U.S. Geol. Survey Flagstaff sheet, scale 1:250,000.
Geology reference: Shoemaker, E. M., 1960, Penetration mechanics of high velocity meteorites, illustrated by Meteor Crater, Arizona: Internat. Geol. Cong., 21st, Copenhagen, 1960, Rept., pt. 18, p. 418–434; geol. map (fig. 1), scale 1:284,000.

Features illustrated (set nos. Ariz. 13 A–B in southeast corner of photographs).—Canyon Diablo (west part of photographs) is carved in the nearly horizontal Kaibab Limestone (Permian), which also underlies wide areas in the northeast third of photograph 13 B. The Moenkopi Formation, which is siltstone and sandstone of Triassic age overlying the Kaibab, forms the darker toned, nearly level surface of the Colorado Plateau around Meteor Crater and extends to within a mile or less of Canyon Diablo. Two sets of vertical joints, trending northeast and northwest, affect the drainage pattern in areas of Kaibab Limestone. Shoemaker ascribes the square, somewhat octagonal shape of Meteor Crater to control by joints; the joint systems that exert the strongest influence on the drainage appear to have been of only secondary importance in the cratering process. Arizona 14 shows the crater at a larger scale.

Ariz. 14. Meteor Crater

County: Coconino.
Lat 35°02′ N.; long 111°01′ W.
Number of photographs: 2.
Photograph scale: 1:15,000.
Focal length: 6 in.
Date flown: Aug. 29, 1963.
Map reference: U.S. Geol. Survey Flagstaff sheet, scale 1:250,000.
Geology reference: Shoemaker, E. M., 1960, Penetration mechanics of high velocity meteorites, illustrated by Meteor Crater, Arizona: Internat. Geol. Cong., 21st, Copenhagen, 1960, Rept., pt. 18, p. 418–434; geol. map (fig. 2), scale 1:24,000.

Features illustrated (set nos. Ariz. 14 A–B in southeast corner of photographs).—Meteor Crater is about 600 feet deep and three-quarters of a mile in diameter. At the large scale of these photographs, the rim, which rises 100–200 feet above the surrounding plain, is seen to have a hummocky surface with scattered large ejecta blocks. The area mantled by debris thrown from the crater can be distinguished from the alluvial surface of the surrounding plain. There is a borrow pit in the rim near the southwest corner of the crater. Beds exposed in the crater walls dip outward away from the crater, roughly parallel with the surface. The talus slopes below the outcrops show centripetal drainage. The central part of the floor is flat and is underlain by playa beds. Arizona 13 shows the crater and adjacent Canyon Diablo at a smaller scale.

Ariz. 15. Braided channels on Sacaton Mountain piedmont

County: Pinal.
Lat 33°01′ N.; long 111°53′ W.
Number of photographs: 3.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Dec. 21, 1957.
Map reference: U.S. Geol. Survey Sacaton Butte and Gila Butte, SE 7½-min quadrangles, scale 1:24,000.
Geology reference: Bryan, Kirk, 1922, Erosion and sedimentation in the Papago country, Arizona: U.S. Geol. Survey Bull. 730, p. 19–90. Tuan, Yi-Fu, 1959, Pediments in southeastern Arizona: California Univ. Pubs. in Geography, v. 13, 163 p.

Features illustrated (set nos. Ariz. 15 A–C in southeast corner of photographs).—These photographs show the piedmont slope on the northwest side of the Sacaton Mountains. Dry braided channels outlined by desert shrubs are conspicuous. The channels curve around small bedrock hills. The form of this piedmont is well shown by comparing these excellent photographs with the detailed topographic maps, mentioned above, that have a 10-foot contour interval. Most of the piedmont is mantled by alluvium. It is not possible to determine on the photographs whether or not the small bedrock hills are surrounded by a narrow pediment.

Ariz. 16. Sacaton Mountains, an inselberge

County: Pinal.
Lat 33°02′ N.; long 111°50′ W.
Number of photographs: 3.
Photograph scale: 1:60,000.
Focal length: 6 in.
Date flown: Apr. 29, 1953.
Map reference: U.S. Geol. Survey Gila Butte, Casa Grande, Sacaton, and Signal Peak 15-min quadrangles, scale 1:62,500.
Geology reference: Bryan, Kirk, 1922, Erosion and sedimentation in the Papago country, Arizona: U.S. Geol. Survey Bull. 730, p. 19–90. Tuan, Yi-Fu, 1959, Pediments in southeastern Arizona: California Univ. Pubs. in Geography, v. 13, 163 p.

Features illustrated (set nos. Ariz. 16 A–C in northeast corner of photographs).—Since Kirk Bryan first applied the term "mountain pediment" to the piedmont that surrounds the Sacaton Mountains, the origin of this and similar features has been widely discussed. These small-scale photographs show the north half of the mountains and the adjacent piedmont from Santa Cruz wash on the west to the flood plain of Little Gila River at Sacaton. The entire piedmont is traversed by closely spaced stream channels.

Ark. 1. Choctaw anticline

County: Scott.
Lat 34°55′ N.; long 94°12′ W.
Number of photographs: 3.
Photograph scale: 1:25,000.
Focal length: 6 in.
Date flown: Nov. 9, 1957.
Map reference: U.S. Geol. Survey Waldron 15-min quadrangle, scale 1:62,500.
Geology reference: Reinemund, J. A., and Danilchik, Walter, 1957, Preliminary geologic map of the Waldron quadrangle and adjacent areas, Scott County, Arkansas: U.S. Geol. Survey Oil and Gas Inv. Map OM–192, scale 1:48,000.

Features illustrated (set nos. Ark. 1 A–C in southwest corner of photographs).—The concentric ridges in the south half of photograph 1 A are largely siltstone and sandstone separated by narrow valleys carved in claystone (Atoka Formation of Pennsylvanian age). The rocks are a part of the east-plunging Choctaw anticline. In the south half of photograph 1 C a small syncline is superposed on the south limb of the anticline. The flood plain of Poteau River (north half of photographs) is hemmed in by sandstone ridges.

Ark. 2. Athens plateau and Novaculite uplift

County: Polk and Howard.
Lat 34°22′ N.; long 94°01′ W.
Number of photographs: 3.
Photograph scale: 1:23,600.
Focal length: 6 in.
Date flown: Feb. 17, 1955.
Map reference: U.S. Geol. Survey Umpire 15-min quadrangle, scale 1:62,500.
Geology reference: Miser, H. D., and Purdue, A. H., 1929, Geology of the De Queen and Caddo Gap quadrangles, Arkansas: U.S. Geol. Survey Bull. 808, 195 p.; geol. map (pl. 3), scale 1:125,000.

Features illustrated (set nos. Ark. 2 A–C in southeast corner of photographs).—Closely folded Stanley Shale of Mississippian age forms a piedmont plateau (photograph 2 A) that has a pronounced east-trending grain and is dissected to a depth of about 100 feet. To the north, west-plunging anticlines of closely folded Arkansas Novaculite of Devonian age form east-trending ridges as much as 500 feet high. The ridges mark the southern limit of the Novaculite uplift. The Blaylock Sandstone of Silurian age is exposed in some of the anticlinal ridges in the north part of photograph 2 C.

Ark. 3. Plunging anticline at Hot Springs

County: Garland.
Lat 34°31′ N.; long 93°06′ W.
Number of photographs: 3.
Photograph scale: 1:18,000.
Focal length: 6 in.
Date flown: Apr. 9, 1965.
Map reference: U.S. Geol. Survey Hot Springs and vicinity 15-min quadrangle, scale 1:62,500.
Geology reference: Purdue, A. H., and Miser, H. D., 1923, Description of the Hot Springs district, Arkansas: U.S. Geol. Survey Geol. Atlas, Folio 215, geol. map, scale 1:62,500. (Out of print.)

Features illustrated (set nos. Ark. 3 A–C in northeast corner of photographs).—Sugarloaf Mountain (north half of photograph 3 A) and West Mountain (south half of same photograph) are held up by Arkansas Novaculite (Devonian) on the limbs of a southwest-plunging anticline. The novaculite on the nose of the fold passes beneath the body of water in the southwest corner of photograph 3 B. Stanley Shale (Mississippian) forms the lowlands surrounding the mountains, and Bigfork Chert (Ordovician) forms the intermontane valley. The two ridges of Sugarloaf Mountain northeast of the road that crosses it owe their existence to a minor fold on the north limb of the anticline.

Ark. 4. Quarries and strip mines in the Arkansas bauxite region

County: Pulaski.
Lat: 34°41′ N.; long 92°16′ W.
Number of photographs: 4.
Photograph scale: 1:18,000.
Focal length: 6 in.
Date flown: Mar. 2, 1960.
Map reference: U.S. Geol. Survey Little Rock 7½-min quadrangle, scale 1:24,000.
Geology reference: Gordon, MacKenzie, Jr., Tracey, J. I., Jr., and Ellis, M. W., 1958, Geology of the Arkansas bauxite region: U.S. Geol. Survey Prof. Paper 299, 268 p.; geol. map (pl. 1), scale 1:31,680.

Features illustrated (set nos. Ark. 4 A–D in northeast corner of photographs).—Smooth wooded hills of nepheline syenite and related igneous rocks are overlain and surrounded by lower Tertiary sand and clay. The bauxite occurs as discontinuous blanketlike deposits on the weathered surface of the nepheline syenite and nearby in the rocks of the Coastal Plain province. A large quarry in syenite is visible in the northwest quadrant of photograph 4 B. Bauxite strip mines are conspicuous in the east half of photograph 4 C.

Calif. 1. Mudflow levees on Shastina

County: Siskiyou.
Lat 41°25′ N.; long 122°14′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Aug. 23, 1944.
Map reference: U.S. Geol. Survey Shasta 15-min quadrangle, scale 1:62,500.
Geology reference: Williams, Howel, 1932, Mount Shasta, a Cascade volcano: Jour. Geology, v. 40, no. 5, p. 417–429.

Features illustrated (set nos. Calif. 1 A–B in southeast corner of photographs).—These mudflow levees on the northwest slope of Shastina, the cone just west of Mount Shasta, extend from the bare debris-covered slope down into the forest. Some levees are forested in their lower courses and are ancient; others are bare and mark channels down which debris has moved in recent years.

Calif. 2. Summit cone of Mount Shasta

County: Siskiyou.
Lat 41°25′ N.; long 122°12′ W.
Number of photographs: 4.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Aug. 23, 1944.
Map reference: U.S. Geol. Survey Shasta 15-min quadrangle, scale 1:62,500.
Geology reference: Williams, Howel, 1932, Mount Shasta, a Cascade volcano: Jour. Geology, v. 40, no. 5, p. 417–429.

Features illustrated (*set nos. Calif. 2 A–D in southeast corner of photographs*).—The summit, altitude 14,162 feet, includes several rocky crags above a central platform. The adjacent rubble-mantled slopes of the volcano are at an angle of about 35°, and the angle decreases gradually downward to the heads of the glaciers that are most extensive on the north and east sides of the cone. Bergschrunds and other crevasses are conspicuous.

Calif. 3. Little Glass Mountain dome

County: Siskiyou.
Lat 41°34′ N.; long 121°41′ W.
Number of photographs: 3.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Aug. 25, 1955.
Map reference: U.S. Geol. Survey Medicine Lake 15-min quadrangle, scale 1:62,500.
Geology reference: Anderson, C. A., 1941, Volcanoes of the Medicine Lake Highland, California: California Univ. Pubs. Geol. Sci., v. 25, no. 7, p. 347–422; map, scale 1:30,000.

Features illustrated (*set nos. Calif. 3 A–C in southeast corner of photographs*).—The rhyolite obsidian flows of Little Glass Mountain present a wrinkled appearance pocked here and there by small depressions presumably formed by small steam explosions. The source of the lava is well marked by an upward bulge of the last extruded material, too viscous to flow outward. The edge of the dome is a steep talus-covered wall more than 100 feet high. The surrounding lowlands are forest covered.

Calif. 4. Glass Mountain obsidian flows and domes

County: Siskiyou.
Lat 41°36′ N.; long 121°30′ W.
Number of photographs: 4.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: July 31, 1955.
Map reference: U.S. Geol. Survey Medicine Lake and Timber Mountain 15-min quadrangles, scale 1:62,500.
Geology reference: Anderson, C. A., 1941, Volcanoes of the Medicine Lake Highland, California: California Univ. Pubs. Geol. Sci., v. 25, no. 7, p. 347–422; map, scale 1:30,000. See plates 5b and 6.

Features illustrated (*set nos. Calif. 4 A–D in southeast corner of photographs*).—These spectacular photographs show that Glass Mountain (photograph 4 B) consists of two obsidian flows, the younger of which runs northeast from a summit dome. Flow structure and steep margins of flows are well shown. The older Hoffman flow lies to the west and supports a moderate growth of pines. Its vent, Mount Hoffman, is outside the area of the photograph. The white patches on the Hoffman flow are pumice that has filled depressions on the flow surface. A line of small domes trends N. 30° W. from Glass Mountain. The flows are probably less than 1,000 years old.

Calif. 5. Domes and mudflows at Lassen Peak

County: Shasta.
Lat 40°30′ N.; long 121°30′ W.
Number of photographs: 3.
Photograph scale: 1:60,000.
Focal length: 6 in.
Date flown: Sept. 30, 1953.
Map reference: U.S. Geol. Survey Lassen Volcanic National Park and vicinity, scale 1:62,500.
Geology reference: Williams, Howel, 1932, Geology of the Lassen Volcanic National Park, California: California Univ. Dept. Geol. Sci. Bull., v. 21, no. 8, p. 195–385; geol. map, scale 1:48,000.

Features illustrated (*set nos. Calif. 5 A–C in northeast corner of photographs*).—Lassen Peak is described by Williams as an elevated crater filling or plugdome surrounded by great banks of talus. Crescent Crater, about a mile northeast of the peak, is a parasitic vent. Chaos Crags, about 2 miles north-northwest of the peak, are cylindrical bodies of viscous dacite from whose northwest side came a great avalanche known as Chaos Jumbles (northwest corner of photograph 5 B). In 1915, Lassen Peak erupted a small mass of lava and generated several large mudflows on its northeast flank that devastated a broad area for a distance of about 3 miles from the peak.

Calif. 6. Yosemite Valley: Domes and glacial features in Little Yosemite Valley

County: Mariposa.
Lat 37°44′ N.; long 119°31′ W.
Number of photographs: 3.
Photograph scale: 1:47,000.
Focal length: 6 in.
Date flown: Aug. 26, 1955.
Map reference: U.S. Geol. Survey Hetch Hetchy Reservoir, Yosemite, Tuolumne Meadows, and Merced Peak 15-min quadrangles, scale 1 62,500.
Geology reference: Matthes, F. E., 1930, Geologic history of the Yosemite Valley: U.S. Geol. Survey Prof. Paper 160, 137 p. Glacial features shown on pl. 29, bedrock geology on pl. 51.

Features illustrated (*set nos. Calif. 6 A–C in northeast corner of photographs*).—Joints in the massive granitic bedrock (Half Dome Quartz Monzonite) are widely spaced. Exfoliation (suggested by arches near northwest corner of photograph 6 C) has produced many domes. The shape of Half Dome (northwest of center photograph 6 B) has been attributed to glacier ice in Tanaya Creek valley that sliced away its northwest part. Nevada Fall of Merced River (2 in. southwest of center of east edge of photograph 6 A and south of Liberty Cap, a small dome) and Vernal Fall (nearly an inch farther west on photograph) are parts of Matthes' "glacial stairway." Lateral moraines on the north side of Little Yosemite Valley (northeast quadrant of photograph 6 B) that divert Sunrise Creek westward were deposited when the terminus of the glacier was far west down Yosemite Valley. Loop moraines on the valley floor (just southeast of center of photograph 6 B) were left during retreat of the ice front. (Calif. 6 and 7 are continuous.)

Calif. 7. Yosemite Valley: Lower valley and Merced Gorge

County: Mariposa.
Lat 37°44′ N.; long 119°38′ W.
Number of photographs: 2.
Photograph scale: 1:47,000.
Focal length: 6 in.
Date flown: Aug. 26, 1955.
Map reference: U.S. Geol. Survey Hetch Hetchy Reservoir and Yosemite 15-min quadrangles, scale 1:62,500.
Geology reference: Matthes, F. E., 1930, Geologic history of the Yosemite Valley: U.S. Geol. Survey Prof. Paper 160, 137 p. Glacial features shown on pl. 29, bedrock geology on pl. 51.

Features illustrated (set nos. Calif. 7 A–B in northeast corner of photographs).—El Capitan (2 in. west of center of east edge of photograph 7 A), a sheer cliff nearly 3,000 feet high (difficult to see in stereo), and Cathedral Rocks face each other across nearly flat Yosemite Valley; here the Merced River flows in a U-shaped glaciated valley. At the west edge of the photograph, the valley is narrow, and in Merced Gorge (southwest quadrant of photograph 7 A, not in stereo) the stream fills the bottom of a V-shaped canyon untouched by ice. Upper Yosemite Fall (just west of Yosemite Point, center of northeast quadrant of photograph 7 B; for stereo, see Calif. 6) is dry in late August. Bedrock is Half Dome Quartz Monzonite; vegetation patterns on ice-scoured bedrock upland show that joints are widely spaced. Wawona Tunnel, on Wawona Road south of Merced River (only east portal seen in stereo), is 0.8 mile long. (Calif. 6 and 7 are continuous.)

Calif. 8. Mono Craters

County: Mono.
Lat 37°53′ N.; long 119°01′ W.
Number of photographs: 2.
Photograph scale: 1:47,200.
Focal length: 6 in.
Date flown: Aug. 10, 1951.
Map reference: U.S. Geol. Survey Mono Craters 15-min quadrangle, scale 1:62,500.
Geology reference: Putnam, W. C., 1949, Quaternary geology of the June Lake district, California: Geol. Soc. America Bull., v. 60, p. 1281–1302.

Features illustrated (set nos. Calif. 8 A–B in northeast corner of photographs).—These photographs show a chain of rhyolitic obsidian domes and flows. Putnam describes them as citadellike structural features whose nearly vertical walls are girdled with a continuous mantle of blocky talus and surmounted by a rampart of obsidian pinnacles. Tahoe moraines are conspicuous in the southwest quadrant of photograph 8 B (not in stereo).

Calif. 9. Rock glaciers along Sherwin Creek

County: Mono.
Lat 37°35′ N.; long 118°56′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Sept. 24, 1944.
Map reference: U.S. Geol. Survey Mount Morrison 15-min quadrangle, scale 1:62,500.
Geology reference: Rinehart, C. D., and Ross, D. C., 1964, Geology and mineral deposits of the Mount Morrison quadrangle, Sierra Nevada, California: U.S. Geol. Survey Prof. Paper 385, p. 74–75, fig. 37; geol. map (pl. 1), scale 1:62,500.

Features illustrated (set nos. Calif. 9 A–B in southeast corner of photographs).—Large inactive rock glacier in northwest quadrant of photograph 9 A. This rock glacier is markedly concave in transverse profile and supports an open forest. Smaller rock glaciers in the southwest quadrant are bare. The bedrock is granodiorite, except in the northeast quadrant where dark-colored beds of hornfels that have a northwest strike are conspicuous.

Calif. 10. Rock glaciers near Mammoth Crest

County: Mono and Fresno.
Lat 37°35′ N.; long 118°58′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Sept. 23, 1944.
Map reference: U.S. Geol. Survey Mount Morrison 15-min quadrangle, scale 1:62,500.
Geology reference: Rinehart, C. D., and Ross, D. C., 1964, Geology and mineral deposits of the Mount Morrison quadrangle, Sierra Nevada, California: U.S. Geol. Survey Prof. Paper 385, p. 74–75; geol. map (pl. 1), scale 1:62,500.

Features illustrated (set nos. Calif. 10 A–B in southeast corner of photographs).—A small rock glacier and several talus aprons are visible in the northwest quadrant of photograph 10 B. The bedrock is steeply dipping Mesozoic volcanic rock that imparts a northwest-trending topographic grain to Mammoth Creek valley in contrast to that of Sherwin Creek in the northeast quadrant where the bedrock is granodiorite. Mammoth Crest passes through the center of this photograph.

Calif. 11. Intersecting moraines near Convict Lake

County: Mono.
Lat 37°37′ N.; long 118°52′ W.
Number of photographs: 2.
Photograph scale: 1:47,200.

Focal length: 6 in.
Date flown: Aug. 10, 1951.
Map reference: U.S. Geol. Survey Mount Morrison 15-min quadrangle, scale 1:62,500.
Geology reference: Rinehart, C. D., and Ross, D. C., 1964, Geology and mineral deposits of the Mount Morrison quadrangle, Sierra Nevada, California: U.S. Geol. Survey Prof. Paper 385, p. 68–70, fig. 34 and pl. 1.

Features illustrated (set nos. Calif. 11 A–B in northeast corner of photographs).—The older moraine consists of a massive embankment whose northeast end is near the center of photograph 11 B. The embankment is elongated east-northeastward parallel with the long axis of Convict Lake (southwest quadrant of same photograph). A sharply defined ridge nested within a more poorly preserved one of about the same height marks the north side of an eastward-moving ice tongue on whose south side next to McGee Mountain only two small remnants remain. The younger moraines (north of Convict Lake) were deposited by glaciers that moved northward across the older more massive moraine. This movement suggests a 90° shift near the terminus in the direction of ice movement of the younger glaciers. The hills in the northwest quadrant of photograph 11 B are composed of rhyolite of Pliocene(?) age. The moraines north of the lake are shown at a larger scale in Calif. 12.

Calif. 12. Moraines north of Convict Lake

County: Mono.
Lat 37°37′ N.; long 118°52′ W.
Number of photographs: 3.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Sept. 24, 1944.
Map reference: U.S. Geol. Survey Mount Morrison 15-min quadrangle, scale 1:62,500.
Geology reference: Rinehart, C. D., and Ross D. C., 1964, Geology and mineral deposits of the Mount Morrison quadrangle, Sierra Nevada, California: U.S. Geol. Survey Prof. Paper 385, p. 68–70, fig. 34.

Features illustrated (set nos. Calif. 12 A–C in southeast corner of photographs).—These photographs show moraines of two glaciations. The younger moraines (northeast quadrant of photograph 12 B) include three groups. The farthest line of advance is marked by a double-crested end moraine, just south of which is a slightly lower recessional moraine. The third group includes smaller nested morainal ridges that begin at a point about halfway between the north end of the lake and the point of maximum advance. A similar sequence is well shown east of the lake. The older moraines consist of a massive embankment east-northeast of the north end of the lake, where the ridges are more rounded and discontinuous than those of the younger glaciation. (See also Calif. 11.)

Calif. 13. McGee Creek moraine offset along Hilton Creek fault

County: Mono.
Lat 37°34′ N.; long 118°47′ W.
Number of photographs: 2.
Photograph scale: 1:47,200.
Focal length: 6 in.
Date flown: Aug. 10, 1951.
Map reference: U.S. Geol. Survey Mount Morrison 15-min quadrangle, scale 1:62,500.
Geology reference: Rinehart, C. D., and Ross D. C., 1964, Geology and mineral deposits of the Mount Morrison quadrangle, Sierra Nevada, California: U.S. Geol. Survey Prof. Paper 385, p. 70, fig. 35, and pl. 1.

Features illustrated (set nos. Calif. 13 A–B in northeast corner of photographs).—Two moraines loop across McGee Creek at a point about a mile beyond the mountain front (northeast quadrant of photograph 13 B). Remnants of the inner and younger moraine occur also along the valley walls in the foothills. The scarp formed by recent movement along the range-front fault is clearly visible crossing both moraines at the mountain front and can be traced to the north and south. A related scarp parallels the highway west of the creek, which has built a small delta in Lake Crowley. The bedrock along the lower part of McGee Creek is largely Paleozoic metamorphic rock and chiefly granodiorite near the headwaters. (Calif. 13 and 14 are continuous.)

Calif. 14. Moraines near Rock Creek and Owens River gorge

County: Mono.
Lat 37°33′ N.; long 118°42′ W.
Number of photographs: 3.
Photograph scale: 1:47,200.
Focal length: 6 in.
Date flown: Aug. 10, 1951.
Map reference: U.S. Geol. Survey Casa Diablo Mountain 15-min quadrangle, scale 1:62,500.
Geology reference: Rinehart, C. D., and Ross, D. C., 1957, Geology of the Casa Diablo Mountain quadrangle, California: U.S. Geol. Survey Geol. Quad. Map GQ–99. Putnam, W. C., 1960, Origin of Rock Creek and Owens River gorges, Mono County, California: California Univ. Pubs. Geol. Sci., v. 34, no. 5, p. 221–280.

Features illustrated (set nos. Calif. 14 A–C in northeast corner of photographs).—Drifts of three glaciations occur along Rock Creek that enters the area at the southwest corner of photograph 14 B. Tioga moraines cross the creek south of the center of photograph 14 C, and the conspicuous moraines near the mouth of the creek are of Tahoe age. A broad area on either side of Rock Creek near the center of the photograph contains patches of Sherwin till, which is older than the Bishop Tuff that forms the wooded tableland in the north half of the photograph. Putnam believes that the headward growth of Owens River (north half of photograph 14 B) captured the drainage from a lake in Long Valley (northwest corner of photograph 14 B). This capture caused the river to carve a deep gorge. Rock Creek that formerly flowed north to Long Valley was captured at a somewhat later date by headward growth of a stream roughly parallel to Owens River, forming a barbed junction. (Calif. 13 and 14 are continuous.)

Calif. 15. Moraines in Mono Creek Valley

County: Fresno.
Lat 37°23′ N.; long 119°00′ W.
Number of photographs: 2.
Photograph scale: 1:47,200.
Focal length: 6 in.
Date flown: Aug. 25, 1951.
Map reference: U.S. Geol. Survey Kaiser Peak and Mount Abbot 15-min quadrangles, scale 1:62,500.
Geology reference: Birman, J. H., 1964, Glacial geology across the crest of the Sierra Nevada, California: Geol. Soc. America Spec. Paper 75, 80 p.; pl. 1 (map of glacial geology), scale 1:62,500.

Features illustrated (set nos. Calif. 15 A–B in northeast corner of photographs).—Moraines of three Wisconsin advances are present on the west side of the crest of the Sierra Nevada. In photograph 15 A, taken before Edison Dam was built, Tioga moraines surround the west end of the valley just east of the center of the photograph. Tahoe moraines are conspicuous on the uplands north of the valley.

Devils Bathtub, on the north edge of the photograph, and Graveyard Meadows, in the northeast corner, are surrounded by moraines of three Wisconsin Glaciations (Tioga, Tenaya, and Tahoe).

Calif. 16. Inverted topography at Table Mountain

County: Fresno and Madera.
Lat 37°01′ N.; long 119°36′ W.
Number of photographs: 3.
Photograph scale: 1:34,680.
Focal length: 6 in.
Date flown: Nov. 14, 1940.
Map reference: U.S. Geol. Survey Millerton Lake and Clovis 15-min quadrangles, scale 1:62,500.
Geology reference: Macdonald, G. A., 1941, Geology of the western Sierra Nevada between the Kings and San Joaquin Rivers, California: California Univ. Dept. Geol. Sci. Bull., v. 26, no. 2, p. 215–286; geol. map, scale 1:62,500.

Features illustrated (set nos. Calif. 16 A–C in northeast corner of photographs).—Table Mountain (center of photograph 16 B) and the adjacent flat-topped hills are erosional remnants of a basalt flow that filled an ancient river channel. The topography is inverted. These remnants exhibit a meanderlike pattern that may be a reflection of meanders of the Pliocene(?) course of San Joaquin River. The bedrock is largely Jurassic crystalline rocks. The present canyon of the river is incised as much as 1,500 feet below the surface of the flows.

Calif. 17. Sierra Nevada and adjacent piedmont near Lone Pine

County: Inyo.
Lat 36°42′ N.; long 118°14′ W.
Number of photographs: 2.
Photograph scale: 1:47,200.
Focal length: 6 in.
Date flown: Sept. 10, 1955.
Map reference: U.S. Geol. Survey Lone Pine and Mount Whitney 15-min quadrangles, scale 1:62,500.
Geology reference: Knopf, Adolph, 1918, A geologic reconnaissance of the Inyo Mountains and the eastern slope of the southern Sierra Nevada, California: U.S. Geol. Survey Prof. Paper 110, 130 p.; geol. map (pl. 2), scale 1:125,000.

Features illustrated (set nos. Calif. 17 A–B in southeast corner of photographs).—Granitic rocks form the east face of the Sierra Nevada fault block that has triangular facets between the canyons emerging from the mountains. A discontinuous fault scarp that cuts unconsolidated materials more or less parallels the mountain front. East of the mountain front, a bajada of coalescing alluvial fans slopes northeast to Owens Valley and is crossed by perennial streams.

Calif. 18. Dikes in granitic rocks, Inyo Mountains

County: Inyo.
Lat 36°58′ N.; long 118°12′ W.
Number of photographs: 2.
Photograph scale: 1:37,400.
Focal length: 6 in.
Date flown: July 17, 1947.
Map reference: U.S. Geol. Survey Independence 15-min quadrangle, scale 1:62,500.
Geology reference: Ross, D. C., 1962, Preliminary geologic map of the Independence quadrangle, Inyo County, California: U.S. Geol. Survey Misc. Geol. Inv. Map MF-254.

Features illustrated (set nos. Calif. 18 A–B in southeast corner of photographs).—Mafic and felsic dikes in granitic rocks of the Inyo Mountains (dark lines in east half of photograph 18 B). White streaks in the granitic terrane are shear zones. The north-northwest-trending fault trace in Owens Valley is marked by dry sag ponds. The dark canal is the Los Angeles aqueduct; the diversion dam shifting the water from the Owens River to the aqueduct is seen in the north part of photograph 18 A.

Calif. 19. Faults in granite and in alluvium along Owens River

County: Inyo.
Lat 36°54′ N.; long 118°09′ W.
Number of photographs: 3.
Photograph scale: 1:37,400.
Focal length: 6 in.
Date flown: July 17, 1947.
Map reference: U.S. Geol. Survey Independence 15-min quadrangle, scale 1:62,500.

Geology reference: Ross, D. C., 1962, Preliminary geologic map of the Independence quadrangle, Inyo County, California: U.S. Geol. Survey Misc. Geol. Inv. Map MF-254.

Features illustrated (set nos. Calif. 19 A–C in southeast corner of photographs).—Northwest-trending faults in a granitic body near the west base of the Inyo Mountains. The prominent lines marking the faults are in part sheared granitic rock that appears light colored on photographs and are in part bands of sagebrush that appear dark in the photographs. This fault zone is virtually parallel to another fault marked by sag ponds in the alluvium on the floor of Owens Valley. There is no obvious faultline along the base of the range. Dark patches are Pennsylvanian carbonate hornfels inclusions or small roof pendants in the granitic rock. Conspicuous abandoned meanders and oxbow lakes are visible on the dry bed of the Owens River.

Calif. 20. Granitic rocks intruded in metasediments near Mazourka Canyon

County: Inyo.
Lat 36°53′ N.; long 118°04′ W.
Number of photographs: 2.
Photograph scale: 1:37,400.
Focal length: 6 in.
Date flown: July 16, 1947.
Map reference: U.S. Geol. Survey Independence 15-min quadrangle, scale 1:62,500.
Geology reference: Ross, D. C., 1962, Preliminary geologic map of the Independence quadrangle, Inyo County, California: U.S. Geol. Survey Misc. Geol. Inv. Map MF-254.

Features illustrated (set nos. Calif. 20 A–B in southeast corner of photographs).—The contact between the granitic rocks and the metamorphosed sedimentary rocks they intrude is well exposed west of Mazourka Canyon (west half of photographs). Granitic rock is also present in the southeast quadrant of photograph 20 B. The sedimentary rocks of Cambrian, Ordovician, Silurian, and Mississippian age strike parallel to Mazourka Canyon and dip steeply. A few mine workings are visible.

Calif. 21. Scarps of Owens Valley earthquake, 1872

County: Inyo.
Lat 36°34′ N.; long 118°03′ W.
Number of photographs: 2.
Photograph scale: 1:47,200.
Focal length: 6 in.
Date flown: Sept. 10, 1955.
Map reference: U.S. Geol. Survey Lone Pine and New York Butte 15-min quadrangles, scale 1:62,500.
Geology reference: Bateman, P. C., 1961, Willard D. Johnson and the strike-slip component of fault movement in the Owens Valley, California, earthquake of 1872: Seismol. Soc. America Bull., v. 51, no. 4, p. 483–493.

Features illustrated (set nos. Calif. 21 A–B in southeast corner of photographs).—Scarps formed during the Owens Valley earthquake of 1872 along the east side of Alabama Hills at Lone Pine, Calif. A small graben south of the town encloses Diaz Lake (southwest quadrant of photograph 21 A). There is a conspicuous joint pattern in the granitic rocks of Alabama Hills southwest of Lone Pine. Dark soft slopes of Alabama Hills west of Lone Pine (not in stereo) are Mesozoic metavolcanic rocks contrasting with bouldery outcrops of granitic rocks to the southwest. Beach ridges on the north side of the dry bed of Owens Lake are in the southeast quadrant of photograph 21 A.

Calif. 22. Desiccation cracks on dry bed of Owens Lake

County: Inyo.
Lat 36°27′ N.; long 117°59′ W.
Number of photographs: 2.
Photograph scale: 1:38,000.
Focal length: 6 in.
Date flown: July 16, 1947.
Map reference: U.S. Geol. Survey Keeler and Olancha 15-min quadrangles, scale 1:62,500.

Features illustrated (set nos. Calif. 22 A–B in southeast corner of photographs).—The patterns formed by these cracks are irregular in plan and varied in size. One large polygon may enclose many smaller ones. Some of the larger, generally rectangular polygons are more than 1,000 feet in longest dimension. Smaller ones, commonly 150–300 feet in diameter, are more nearly equidimensional and many sided.

Calif. 23. East face of Panamint Range near Aguereberry Point

County: Inyo.
Lat 36°22′ N.; long 117°00′ W.
Number of photographs: 3.
Photograph scale: 1:60,000.
Focal length: 6 in.
Date flown: Oct. 11, 1952.
Map reference: U.S. Geol. Survey Emigrant Canyon and Furnace Creek 15-min quadrangles, scale 1:62,500.
Geology reference: Hunt, C. B., and Mabey, D. R., 1966, Stratigraphy and structure, Death Valley, California: U.S. Geol. Survey Prof. Paper 494-A, 162 p.; geol. map (pl. 1), scale 1:96,000.

Features illustrated (set nos. Calif 23 A–C in southeast corner of photographs).—East face of Panamint Range from Aguereberry Point (altitude 6,433 ft, near center of west edge of photograph 23 B) to the floor of Death Valley. Trail Canyon (southwest quadrant of photograph 23 B) cuts through a thick sequence of generally east-dipping sedimentary rocks of Cambrian age to emerge on a broad fan whose toe is outside the area shown. Dark areas on fans are desert pavement. The salt-crusted playa (northeast quadrant) in this area is largely rock salt. Near the playa, the two black hills and the white formation at south end of one hill are Tertiary volcanic rocks faulted against the Paleozoic rocks.

Calif. 24. Death Valley saltpan and Panamint Range

County: Inyo.
Lat 36°15′ N.; long 116°55′ W.
Number of photographs: 2.
Photograph scale: 1:48,000.
Focal length: 6 in.
Date flown: Dec. 2, 1948.
Map reference: U.S. Geol. Survey Bennetts Well and Furnace Creek 15-min quadrangles, scale 1:62,500.
Geology reference: Hunt, C. B., and Mabey, D. R., 1966, Stratigraphy and structure, Death Valley, California: U.S. Geol. Survey Prof. Paper 494–A, 162 p.; geol. map (pl. 1), scale 1:96,000.

Features illustrated (set nos. Calif. 24 A–B in southeast corner of photographs).—Apex of Panamint Range fan at the mouth of Death Valley Canyon is at the center point of the western edge of photograph 24 B. Fan segments of at least three different ages are visible: (1) Deeply dissected fan-head mesas north and south of Death Valley Canyon wash, (2) areas of desert pavement (dark colored) on fan segments that are only slightly dissected, and (3) the light-colored modern washes that carry the very occasional floods of the present day. In the saltpan (east half of the photographs) can be seen the chloride, sulfate, and carbonate zones. Phreatophytes are in the carbonate zone, in a spring zone along the edge of the saltpan. The sulfate zone is a narrow discontinuous belt on the panward side of the desert shrubs. Most of the saltpan is rock salt with salt-crusted surfaces that are subject to flooding.

Calif. 25. Badwater, Death Valley

County: Inyo.
Lat 36°15′ N.; long 116°45′ W.
Number of photographs: 2.
Photograph scale: 1:48,000.
Focal length: 6 in.
Date flown: Nov. 27, 1948.
Map reference: U.S. Geol. Survey Furnace Creek, Bennetts Well, Ryan, and Funeral Peak 15-min quadrangles, scale 1:62,500.
Geology reference: Drewes, Harald, 1963, Geology of the Funeral Peak quadrangle, California, on the east flank of Death Valley: U.S. Geol. Survey Prof. Paper 413, 78 p.; geol. map, scale 1:62,500. Hunt, C. B., Robinson, T. W., Bowles, W. A., and Washburn, A. L., 1966, Hydrologic basin, Death Valley, California: U.S. Geol. Survey Prof. Paper 494–B, 138 p.; geol. map (pl. 1), scale 1:96,000.

Features illustrated (set nos. Calif. 25 A–B in southeast corner of photographs).—Badwater, almost the lowest point in the United States, is a spring fed sulfate marsh in the reentrant on the north side of the fan in the center of photograph 25 B. The broad white area west of Badwater is subject to flooding and is crusted with rock salt. North of this area, extending to the foot of the gravel fan, is massive rock salt; to the south is rock salt that has been smoothed by flooding (C. B. Hunt, written commun., March 1964). At right is the faulted front of the Black Mountains; the Badwater Turtleback—metasedimentary rocks of Precambrian age—is overlapped at the north by volcanic rocks of Tertiary age.

Calif. 26. Death Valley saltpan and Black Mountain front

County: Inyo.
Lat 36°07′ N.; long 116°45′ W.
Number of photographs: 2.
Photograph scale: 1:48,000.
Focal length: 6 in.
Date flown: Nov. 27, 1948.
Map reference: U.S. Geol. Survey Funeral Peak and Bennetts Well 15-min quadrangles, scale 1:62,500.
Geology reference: Drewes, Harald, 1963, Geology of the Funeral Peak quadrangle, California, on the east flank of Death Valley: U.S. Geol. Survey Prof. Paper 413, 78 p.; geol. map, scale 1:62,500.

Features illustrated (set nos. Calif. 26 A–B in southeast corner of photographs).—Precipitous fault scarps with gullied surfaces form prominent triangular facets. Copper Canyon in the southeast quadrant of photograph 26 A cuts through Tertiary clastic sediments, downfaulted in Precambrian metamorphic rocks, to emerge on a symmetrical alluvial fan. Coffin Canyon empties onto a small fan near the center of the same photograph. White beds in the northeast quadrant of photograph 26 B are siltstone and evaporates that include a dark band of volcanic rocks. Silt and evaporates on the valley floor are traversed by anastomosing channels, distributaries of the Amargosa River.

Calif. 27. Landslides on Bat Mountain piedmont

County: Inyo.
Lat 36°20′ N.; long 116°29′ W.
Number of photographs: 2.
Photograph scale: 1:48,000.
Focal length: 6 in.
Date flown: Dec. 2, 1948.
Map reference: U.S. Geol. Survey Ash Meadows and Ryan 15-min quadrangles, scale 1:62,500.
Geology reference: Denny, C. S., 1961, Landslides east of Funeral Mountains, near Death Valley Junction, California, *in* Short papers in the geologic and hydrologic sciences: U.S. Geol. Survey Prof. Paper 424–D, p. D85–D89.

Features illustrated (set nos. Calif. 27 A–B in southeast corner of photographs).—East-dipping Paleozoic sedimentary rocks and Tertiary arid-basin sediments form a fault-block mountain surrounded by a piedmont of coalescing alluvial fans. Abandoned segments of fans are capped by desert pavement that in most places appears darker than the surrounding piedmont owing to presence of desert varnish on the individual stones. Pavements are dissected by meandering washes that head on piedmont. Several landslides east of the center of photograph 27 B form light-colored digitiform ridges on piedmont. The snout of a conspicuous landslide about 3 inches south of the center of photograph 27 B extends eastward beyond the mountain front. Landslide debris is in part rubble and in part megabreccia and rests either on Tertiary rocks or on Quaternary alluvial deposits.

Calif. 28. Piracy on Shadow Mountain fan

County: Inyo.
Lat 36°17′ N.; long 116°17′ W.
Number of photographs: 2.
Photograph scale: 1:48,000.
Focal length: 6 in.
Date flown: Nov. 25, 1948.
Map reference: U.S. Geol. Survey Ash Meadows 15-min quadrangle, scale 1:62,500.
Geology reference: Denny, C. S., 1965, Alluvial fans in the Death Valley region, California and Nevada: U.S. Geol. Survey Prof. Paper 466, 62 p.; map (pl. 1), scale 1:24,000. Denny, C. S., and Drewes, Harald, 1965, Geology of Ash Meadows quadrangle, Nevada-California: U.S. Geol. Survey Bull. 1181–L, p. L1–L56; geol. map (pl. 1), scale 1:62,500.

Features illustrated (set nos. Calif. 28 A–B in southeast corner of photographs).—The fan heads in a reentrant on the northwest side of Shadow Mountain (near center of photograph 28 A) and slopes first to the northwest and then westward. Down-fan it merges with adjacent fans to form a complex piedmont (near the northeast-trending Old Traction Road).

Floods from the mountain follow broad anastomosing channels separated by abandoned segments of the fan that are mantled by dark-colored desert pavement and dissected by meandering washes that head on the piedmont. Piracy has taken place, the point of diversion being about 3 inches north-northwest of the center of the south edge of photograph 28 B. Dissection of the piedmont caused a northwest-flowing wash heading in the mountains east of the fan to be diverted, only a short time ago, into the headwaters of a west-southwest-trending meandering wash that is incised about 20 feet below surface of adjacent pavement.

Calif. 29. A thrust-faulted anticline in the Orchard Peak area

County: Kern.
Lat 35°43′ N.; long 120°06′ W.
Number of photographs: 3.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Apr. 11, 1950.
Map reference: U.S. Geol. Survey Sawtooth Ridge 7½-min quadrangle, scale 1:24,000.
Geology reference: Marsh, O. T., 1960, Geology of the Orchard Peak area, California: California Div. Mines Spec. Rept. 62, 42 p.; geol. map (pl. 1), scale 1:35,800.

Features illustrated (set nos. Calif. 29 A–C in southeast corner of photographs).—The Avenal Ridge piercement anticline trends west-northwest across the northeast quadrant of photograph 29 C. Its core of white bentonite and tuffaceous shale (Jurassic?) contrasts with the surrounding darker Cretaceous rocks. The axis of a conspicuous syncline extends east-southeast through the center of the same photograph. The dark rocks forming the ridge on the north limb of the anticline (Bluestone Ridge) are the upper plate of the south-moving Hex thrust, the trace of which turns northward near the center of photograph 29 B. The traces of other thrust faults, of normal faults, and a klippe can also be seen by reference to Marsh's map.

Calif. 30. Horizontal movement on San Andreas fault

County: San Luis Obispo.
Lat 35°16′ N.; long 119°50′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: July 22, 1957.
Map reference: U.S. Geol. Survey McKittrick Summit and Painted Rock 7½-min quadrangles, scale 1:24,000.
Geology reference: Hackel, Otto, and others, 1962, Geology of Carrizo Plains and San Andreas fault: San Joaquin Geol. Soc. Guidebook, 52 p., Stop 5, fig. 2; geol. map (pl. 1), scale 1:125,000.

Features illustrated (set nos. Calif. 30 A–B in southeast corner of photographs).—Photographs show offset drainage, well-defined scarps, and trenches in Quaternary deposits along the trace of San Andreas fault and subsidiary faults. The area slopes gently to the southwest to the Carrizo Plain and is crossed by parallel intermittent streams that locally meander. The streams are incised northeast of the trace of the fault.

Calif. 31. Elkhorn Scarp, San Andreas fault

County: San Luis Obispo.
Lat 35°07′ N.; long 119°40′ W.
Number of photographs: 3.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Aug. 2, 1957.
Map reference: U.S. Geol. Survey Wells Ranch and Panorama Hills 7½-min quadrangles, scale 1:24,000.
Geology reference: Hackel, Otto, and others, 1962, Geology of the Carriso Plains and San Andreas fault: San Joaquin Geol. Soc. Guidebook, 52 p.; geol. map (pl. 1), scale t:125,000. Hill, M. L., and Dibblee, T. W., Jr., t953, San Andreas, Garlock, and Big Pine faults, California: Geol. Soc. America Bull., v. 64, no. 4, p. 443–458; see fig. 1.

Features illustrated (set nos. Calif. 31 A–C in southeast corner of photographs).—Right lateral offset of drainage lines by the San Andreas fault on the southwest side of Temblor Range where a maximum of 3,000 feet of displacement has occurred through recent movements on the fault.

Calif. 32. Shorelines and fault scarps at Searles Lake

County: San Bernardino.
Lat 35°45′ N.; long 117°14′ W.
Number of photographs: 2.
Photograph scale: 1:37,400.
Focal length: 6 in.
Date flown: July 14, 1947.
Map reference: U.S. Geol. Survey Searles Lake, Trona, Wingate Pass, and Manly Peak 15-min quadrangles, scale 1:62,500.
Geology reference: Jennings, C. W., Burnett, J. L., and Troxel, B. W., 1962, Geologic map of California, Trona sheet: California Div. Mines and Geology.

Features illustrated (set nos. Calif. 32 A–B in southeast corner of photographs).—Photographs show differences in expression of shorelines of late Pleistocene Searles Lake between areas where waves worked on bedrock and where lake abutted against unconsolidated upper Cenozoic gravels. In the northwest quadrant of photograph 32 A, the conspicuous strandlines are on the alluvial fans, whereas on bedrock only faint topographic features are visible.

Several low 10- to 20-foot-high fault scarps are visible in the southern half of photograph 32 A just west of the mountain front. The scarps cut all but the most recent gravels in the alluvial washes and in stereoscopic view can be seen to trend diagonally up the slope (northward) in contrast to the shorelines which contour the slope (G. I. Smith, written commun., March 1964).

Calif. 33. Cima Dome, Mojave Desert

County: San Bernardino.
Lat 35°17′ N.; long 115°35′ W.
Number of photographs: 2.
Photograph scale: 1:47,200.
Focal length: 6 in.
Date flown: Apr. 14, 1953.
Map reference: U.S. Geol. Survey Mescal Range and Kelso 15-min quadrangles, scale 1:62,500.
Geology reference: Sharp, R. P., 1957, Geomorphology of Cima Dome, Mojave Desert, California: Geol. Soc. America Bull., v. 68, no. 3, p. 273–290.

Features illustrated (set nos. Calif. 33 A–B in southeast corner of photographs).—This remarkably smooth symmetrical alluvium-fringed rock dome is the prototype of W. M. Davis' granitic desert dome. Numerous outcrops of quartz monzonite can be seen on the dome. Teutonia Peak lies just to the northeast of the summit. The slopes of the dome are traversed by many shallow and closely spaced anastomosing channels. (Calif. 34 overlaps photograph 33 A.)

Calif. 34. Granitic dome and cinder cones near Rainbow Wells

County: San Bernardino.
Lat 35°15′ N.; long 115°40′ W.
Number of photographs: 3.
Photograph scale: 1:54,000.
Focal length: 6 in.
Date flown: Mar. 7, 1954.
Map reference: U.S. Geol. Survey Mescal Range and Kelso 15-min quadrangles, scale 1:62,500.
Geology reference: Sharp, R. P., 1957, Geomorphology of Cima Dome, Mojave Desert, California: Geol. Soc. America Bull., v. 68, no. 3, p. 273–290.

Features illustrated (set nos. Calif. 34 A–C in northeast corner of photographs).—A small granitic dome about 2 miles in diameter (southwest quadrant of photograph 34 A) has virtually straight slopes mantled by a thin layer of detrital gruss. Remnants of Quaternary basalt flows and cinder cones lie on the western flanks of the dome. The slopes of the dome and that of the larger one to the northeast (Cima Dome) are traversed by shallow and closely spaced anastomosing channels. (Calif. 33 overlaps photograph 34 A.)

Calif. 35. Stabilization of sand dunes, San Miguel Island

County: Santa Barbara.
Lat 34°02′ N.; long 120°23′ W.
Number of photographs: 2.
Photograph scale: 1:60,000.
Focal length: 6 in.
Date flown: Apr. 1, 1960.
Map reference: U.S. Geol. Survey San Miguel Island East and San Miguel Island West 7½-min quadrangles, scale 1:24,000.
Geology reference: Bremner, C. St. J., 1933, Geology of San Miguel Island, Santa Barbara County, California: Santa Barbara Mus. Nat. History, Occasional Papers 2, 23 p.; see pl. 1.

Features illustrated (set nos. Calif. 35 A–B in southwest corner of photographs).—San Miguel Island has a striking set of longitudinal dunes formed by the prevailing northwest winds. Some of the dunes extend clear across the island, a distance ranging from 2 to 4 miles. The island was originally covered by a dense growth of brush, but about 1880, cattle and sheep began to graze and much of the vegetation was destroyed. When Bremner studied the area (see his photomosaic, pl. 1, made from photographs taken in 1929), most of the island was covered by actively moving sand. This stereoscopic pair, taken in 1960, suggests partial stabilization of the dunes since 1929. The island is underlain largely by northeast-dipping Eocene sedimentary rocks that form a rolling upland 400–500 feet above sea level.

Calif. 36. Erosion and deposition near Point Mugu

County: Ventura.
Lat 34°05′ N.; long 119°03′ W.
Number of photographs: 2.
Photograph scale: 1:24,000.
Focal length: 6 in.
Date flown: Aug. 20, 1947.
Map reference: U.S. Geol. Survey Point Mugu 7½-min quadrangle, scale 1:24,000.
Geology reference: Inman, D. L., 1954, Beach and shore processes along the southern California coast, *in* Jahns, R. H., ed., Geology of southern California: California Div. Mines

Bull. 170, chap. 5, p. 29–34, fig. 1. [Bedrock geology shown on map sheet 8.]

Features illustrated (set nos. Calif. 36 A–B in northeast corner of photographs).—Point Mugu at the west end of the Santa Monica Mountains forms a natural obstruction which interrupts the littoral drift of sand eastward and thus causes accretion. A wide beach or baymouth bar has formed west of the point on the upcurrent side, and cliff erosion and the building of a few pocket beaches has taken place down current where the supply of sand is diminished. The eastward drift of sediment offshore can be seen east of Point Mugu (southeast quadrant of photograph 36 B). Northward-dipping Miocene shale and conglomerate intruded by diabase form the mountains.

Calif. 37. Dissected marine terraces at Point Dume

County: Los Angeles.
Lat 34°01′ N.; long 118°48′ W.
Number of photographs: 2.
Photograph scale: 1:24,000.
Focal length: 6 in.
Date flown: Aug. 21, 1947.
Map reference: U.S. Geol. Survey Point Dume 7½-min quadrangle, scale 1:24,000.
Geology reference: Putnam, W. C., 1954, Marine terraces of the Ventura region and the Santa Monica Mountains, California, *in* Jahns, R. H., ed., Geology of southern California: California Div. Mines Bull. 170, chap. 5, p. 45–48, fig. 1.

Features illustrated (set nos. Calif. 37 A–B in northeast corner of photographs).—Point Dume, an ancient stack, is on a marine terrace more than 100 feet above sea level. Several other narrow terraces can be seen. The treads are conspicuous, but the risers are gently sloping; any sea cliffs that were initially present have been obscured by seaward-sloping blankets of alluvial-fan gravels. In many places the gravels make a continuously sloping surface from one terrace down to a level three or four treads lower, and thus completely obscure intervening terraces.

Calif. 38. Marine terraces of the Palos Verdes Hills

County: Los Angeles.
Lat 33°46′ N.; long 118°25′ W
Number of photographs: 2.
Photograph scale: 1:30,000.
Focal length: 6 in.
Date flown: Feb. 28, 1963.
Map reference: U.S. Geol. Survey Redondo Beach 7½-min quadrangle, scale 1:24,000.
Geology reference: Woodring, W. P., Bramlette, M. N., and Kew, W. S. W., 1946, Geology and paleontology of Palos Verdes Hills, California: U.S. Geol. Survey Prof. Paper 207, 145 p.; see pls. 22–26.

Features illustrated (set nos. Calif. 38 A–B in northeast corner of photographs).—Ten marine terraces ranging in altitude from approximately 100 to 1,000 feet have been mapped by Woodring and others within the area shown in these photographs; at least four are easily seen. On this west-facing windward coast the prevailing bedrock is hard Miocene cherty shale (part of the Monterey Shale) which forms open folds. The apparent merging of the terraces both in plan and in profile is due to the cover of nonmarine debris that has accumulated on the platforms following emergence.

Calif. 39. Barchan dunes west of Salton Sea

County: Imperial.
Lat 33°11′ N.; long 115°52′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 6 in.
Date flown: Nov. 10, 1959.
Map reference: U.S. Geol. Survey Kane Spring NE. and Kane Spring NW. 7½-min quadrangles, scale 1:24,000.
Geology reference: Long, J. T., and Sharp, R. P., 1964, Barchan-dune movement in Imperial Valley, California: Geol. Soc. America Bull., v. 75, no. 2, p. 149–156.

Features illustrated (set nos. Calif. 39 A–B in southeast corner of photographs).—These dunes, open to the east, range in size horn to horn from about 150 to 800 feet and in height from about 10 to 30 feet. The dunes rest on a smooth gently sloping plain that descends to the Salton Sea. The ground between the dunes has a patchy residual armor of stones. These excellent photographs cover most of the barchan dunes south of the landing strip shown in figure 1 of Long and Sharp's paper. Movement of these dunes ranged from 325 to 925 feet over a 7-year period from 1956 to 1963.

Calif. 40. Marine terraces, San Clemente Island

County: Los Angeles.
Lat 32°53′ N.; long 118°30′ W.
Number of photographs: 2.
Photograph scale: 1:63,000.
Focal length: 6 in.
Date flown: Feb. 3, 1955.
Map reference: U.S. Geol. Survey San Clemente Island Central and San Clemente Island South 7½-min quadrangles, scale 1:24,000.
Geology reference: Olmsted, F. H., 1958, Geologic reconnaissance of San Clemente Island, California: U.S. Geol. Survey Bull. 1071–B, p. 55–68; geol. map (pl. 1), scale 1:31,680.

Features illustrated (set nos. Calif. 40 A–B in south corner of photographs).—A sequence of very gently dipping Miocene volcanics forms this long and narrow island—length about 21 miles, width as much as 4 miles—that rises almost 2,000 feet above sea level. The northeast slope is steep, but on the gentler southwest slope is a spectacular flight of marine terraces of Pleistocene age. The northwest-trending axial drainage divide of the island is close to the northeast coast. The terraces on the southwest slope are notched by steep-sided gullies and canyons, the latter as much as 500 feet deep. The rocky shore is in many places a cliff. A segment of the terraced southwest slope near Eel Point is shown in Calif. 41.

Calif. 41. Marine terraces near Eel Point, San Clemente Island

County: Los Angeles.
Lat 32°56′ N.; long 118°31′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Feb. 19, 1954.
Map reference: U.S. Geol. Survey San Clemente Island Central 7½-min quadrangle, scale 1:24,000.
Geology reference: Olmsted, F. H., 1958, Geologic reconnaissance of San Clemente Island, California: U.S. Geol. Survey Bull. 1071-B, p. 55-68; geol. map (pl. 1), scale 1:31,680.

Features illustrated (set nos. Calif. 41 A-B in east corner of photographs).—These photographs show the marine terraces on the southwest slope of the island near the airfield. The terraces are discontinuous. The risers are steep or clifflike, commonly 20-100 feet high. The treads are gently sloping; some are narrow, others as much as 1,000 feet wide. All the treads are more or less mantled by younger alluvial and colluvial material. Calif. 40 shows most of the island.

Colo. 1. Piracy at the Lindenmeier archaeologic site

County: Weld.
Lat 40°58′ N.; long 105°06′ W.
Number of photographs: 2.
Photograph scale: 1:27,700.
Focal length: 5.2 in.
Date flown: June 16, 1947.
Map reference: U.S. Geol. Survey Greeley sheet, scale 1:250,000.
Geology reference: Bryan, Kirk, and Ray, L. L., 1940, Geologic antiquity of the Lindenmeier site in Colorado: Smithsonian Misc. Colln., v. 99, no. 2, 76 p. Wormington, H. M., 1957, Ancient man in North America: Denver Mus. Nat. History Pop. Ser. 4, p. 31-39.

Features illustrated (set nos. Colo. 1 A-B in southeast corner of photographs).—A south-facing escarpment formed in Oligocene clay passes through the center of photograph 1 B. The Lindenmeier site is along an east-draining gully just north of the escarpment, about 0.6 inch east of the center of photograph 1 B. When Folsom man lived here nearly 11,000 years ago, the small east-trending valley at the site was drained eastward past the cultivated field near the southeast corner of photograph 1 A. The ancestral stream was later beheaded by a south-flowing stream working headward (northward) through the escarpment (at a point about midway between center and west edge of photograph 1 B). North of the escarpment, gravel-capped interfluves are remnants of the Spottlewood pediment of probable early Pleistocene age, a part of the High Plains. The area south of the escarpment is near the northwest corner of the Colorado piedmont.

Colo. 2. Cirques and glaciers in Rocky Mountain National Park

County: Larimer.
Lat 40°20′ N.; long 105°38′ W.
Number of photographs: 5.
Photograph scale: 1:46,000.
Focal length: 6 in.
Date flown: September 1953.
Map reference: U.S. Geol. Survey Trail Ridge, Estes Park, McHenrys Peak, and Longs Peak 7½-min quadrangles, scale 1:24,000.
Geology reference: Richmond, G. M., 1960, Glaciation of the east slope of Rocky Mountain National Park, Colorado: Geol. Soc. America Bull., v. 71, no. 9, p. 1371-1382.

Features illustrated (set nos. Colo. 2 A-E in southeast corner of photographs).—Cirques containing small glaciers just east of the Continental Divide, Rocky Mountain National Park. Taylor, Andrews, Tyndall, and several unnamed glaciers are visible in the northwest quadrant of photograph 2 B, and Longs Peak is in southeast quadrant. The Pinedale moraines surrounding Glacier Basin are in the southeast quadrant of photograph 2 D, and those in Moraine Park are conspicuous due east of the center. Horseshoe Park and Trail Ridge Road are in the north half of photograph 2 E.

Colo. 3. Hogbacks along Rocky Mountain front near Golden

County: Jefferson.
Lat 39°50′ N.; long 105°15′ W.
Number of photographs: 3.
Photograph scale: 1:63,360.
Focal length: 6 in.
Date flown: Sept. 21, 1953.
Map reference: U.S. Geol. Survey Ralston Buttes, Golden, Eldorado Springs, and Louisville 7½-min quadrangles, scale 1:24,000.
Geology reference: Van Horn, Richard, 1957, Bedrock geology of the Golden quadrangle, Colorado: U.S. Geol. Survey Geol. Quad. Map GQ-103. Sheridan, D. M., Maxwell, C. H., Albee, A. L., and Van Horn, Richard, 1958, Preliminary map of bedrock geology of the Ralston Buttes quadrangle, Jefferson County, Colorado: U.S. Geol. Survey Mineral Inv. Field Studies Map MF-179.

Features illustrated (set nos. Colo. 3 A-C in southeast corner of photographs).—Sandstone hogbacks are locally folded and faulted. These upper Paleozoic and Mesozoic rocks rest unconformably on Precambrian schist and gneiss. The ridge inclosing Upper Long Lake just east of the center of photograph 3 B is a monzonite dike. The hogback northeast of the dam is partly truncated by a pediment in the northeast quadrant of the same photograph. The butte northeast of Golden (southeast quadrant photograph 3 B) is capped by latite lavas; small monzonite intrusions form hills between it and the monzonite dike. Water in Ralston Reservoir (near center of photograph 3 B) is muddy.

Colo. 4. Imminent stream capture near Red Rock Canyon

County: Montrose.
Lat 38°34′ N.; long 107°47′ W.
Number of photographs: 2.
Photograph scale: 1:28,400.
Focal length: 6 in.
Date flown: Aug. 1, 1950.
Map reference: U.S. Geol. Survey Red Rock Canyon 7½-min quadrangle, scale 1:24,000.

Features illustrated (set nos. Colo. 4 A–B in northeast corner of photographs).—A cultivated valley drains northwestward to center of photograph 4 B where it crosses a major faultline and enters the head of Red Rock Canyon which empties into the Black Canyon of the Gunnison in the northwest quadrant. The northern half of photograph 4 B is underlain by Precambrian rocks that north of the Gunnison River show a vertical foliation and in the northwest quadrant are overlain unconformably by the Entrada Sandstone. The cultivated valley in the southeast quadrant is being encroached on by gullies eroding headward (northeastward) from the badlands developed on semiconsolidated Mancos Shale in the southwest quadrant. Stream capture is imminent at several points (W. R. Hansen, written commun., February 1964).

Colo. 5. Rock glaciers in Sawatch Range

County: Chaffee and Gunnison.
Lat 38°55′ N.; long 106°28′ W.
Number of photographs: 2.
Photograph scale: 1:18,400.
Date flown: Sept. 24, 1956.
Map reference: U.S. Geol. Survey Mount Harvard 15-min quadrangle, scale 1:62,500.

Features illustrated (set nos. Colo. 5 A–B in northeast corner of photographs).—Rock glaciers in cirques on the north side of the Continental Divide show both longitudinal and transverse ridges and furrows. The glaciers are inactive. Some cirques contain rock-basin lakes or tarns. The bedrock is granodiorite (Fred Barker and M. R. Brock, written commun., February 1964).

Colo. 6. Linear scarps on the Sage Plain

County: Dolores.
Lat 37°48′ N.; long 108°59′ W.
Number of photographs: 2.
Photograph scale: 1:27,230.
Focal length: 5.2 in.
Date flown: Sept. 15, 1947.
Map reference: U.S. Geol. Survey Cortez sheet, scale 1:250,000.
Geology reference: Shawe, D. R., 1963, Possible wind-erosion origin of linear scarps of the Sage Plain, southwestern Colorado, *in* Short papers in geology and hydrology: U.S. Geol. Survey Prof. Paper 475–C, p. C138–C141, fig. 95.2.

Features illustrated (set nos. Colo. 6 A–B in southeast corner of photographs).—Low straight subparallel scarps in Pleistocene loess bound elongate flat areas oriented about N. 25° E. Swales between the flats are probably the result of deflation by the prevailing southwesterly winds.

Colo. 7. Canyons at Mesa Verde

County: Montezuma.
Lat 37°15′ N.; long 108°25′ W.
Number of photographs: 5.
Photograph scale: 1:60,000.
Focal length: 6 in.
Date flown: Nov. 9, 1954.
Map reference: U.S. Geol. Survey topographic map of Mesa Verde National Park, Montezuma County, Colo., scale 1:31,250.
Geology reference: Wanek, A. A., 1959, Geology and fuel resources of the Mesa Verde area, Montezuma and La Plata Counties, Colorado: U.S. Geol. Survey Bull. 1072–M, p. 667–721; geol. map (pl. 49), scale 1:63,360.

Features illustrated (set nos. Colo. 7 A–E in southeast corner of photographs).—Mesa Verde is capped by massive sandstone that rests on less resistant sandstone, shale, and coal beds. The strata dip gently to the south and are of Late Cretaceous age. The great alcoves at the heads and along the sides of the canyons are sites of ancient cliff dwellings, none of which can actually be seen in these photographs. The canyons shallow northward and are cut off by a prominent north-facing escarpment that leads down to a broad valley along Dry Arroyo (northwest quadrant of photograph 7 D). The badlands south of the arroyo are carved in shale; the low wooded hills adjacent to the arroyo are sandstone that underlies the shale.

Colo. 8. Rock glaciers in Silver and Pierson Basins

County: Ouray and San Miguel.
Lat 37°58′ N.; long 107°43′ W.
Number of photographs: 3.
Photograph scale: 1:37,400.
Focal length: 6 in.
Date flown: Sept. 9, 1951.
Map reference: U.S. Geol. Survey Ironton, Telluride, Montrose, and Ouray 7½-min quadrangles, scale 1:24,000.
Geology reference: Burbank, W. S., and Luedke, R. G., 1964, Geology of the Ironton quadrangle: U.S. Geol. Survey Geol. Quad. Map GQ–291. Howe, Ernest, 1909, Landslides in the San Juan Mountains, Colorado: U.S. Geol. Survey Prof. Paper 67, 58 p.

Features illustrated (set nos. Colo. 8 A–C in northeast corner of photographs).—Many rock glaciers occur in the high cirques of the western San Juan Mountains. Those in Pierson Basin and in Silver Basin (southwest quadrant of photograph 8 C) adjacent to Sneffels Creek near Ouray were mapped and photographed many years ago by Howe who called them "rock streams." (See Howe, 1909, p. 31–34, fig. 2, and pls. 10–13). These lobate masses of rock debris are characterized by steep sides and deeply furrowed top with crescentic furrows roughly parallel to the outline of the mass. Some rock glaciers are known to have ice cores. The country rock is bedded volcanic flows, tuffs, and breccias intruded by numerous igneous dikes and irregularly shaped plutons and cut by many faults and mineralized fissures.

Colo. 9. Slumgullion earthflow

County: Hinsdale.
Lat 37°59′ N.; long 107°16′ W.
Number of photographs: 2.
Photograph scale: 1:40,000.
Focal length: 8.25 in.
Date flown: Sept. 27, 1951.
Map reference: U.S. Geol. Survey Durango sheet, scale 1:250,000.
Geology reference: Howe, Ernest, 1909, Landslides in the San Juan Mountains, Colorado: U.S. Geol. Survey Prof. Paper 67, p. 40–41, pl. 20*B*. Crandell, D. R., and Varnes, D. J., 1960, Slumgullion earthflow and earth slide near Lake City, Colorado [abs.]: Geol. Soc. America Bull., v. 71, no. 12, pt. 2, p. 1846.

Features illustrated (set nos. Colo. 9 A–B in northeast corner of photographs).—This prehistoric earthflow descended the east slope of the valley of Lake Fork Gunnison River and dammed this north-flowing river to form Lake San Cristobal. The lower downstream third of the earthflow is stable and contains wood that has a radiocarbon age of about 700 years. The upper two-thirds is being overridden by an active earthslide (northeast quadrant of photograph 9 A, largely outside area visible in stereo). The oldest tree found on the active part is 330 years old (1960).

Colo. 10. Great Sand Dunes, San Luis Valley

County: Saguache and Alamosa.
Lat 37°47′ N.; long 105°33′ W.
Number of photographs: 3.
Photograph scale: 1:53,000.
Focal length: 6 in.
Date flown: Oct. 5, 1953.
Map reference: U.S. Geol. Survey Trinidad sheet, scale 1:250,000.
Geology reference: Merk, G. P., 1960, Great Sand Dunes of Colorado, *in* Weimer, R. J., and Haun, J. D., eds., Guide to the geology of Colorado: Geol. Soc. America, Rocky Mtn. Assoc. Geologists, Colorado Sci. Soc., p. 127–129.

Features illustrated (set nos. Colo. 10 A–C in southeast corner of photographs).—The Great Sand Dunes lie near the east side of the broad San Luis Valley, separated from the west base of the Sangre de Cristo Mountains only by Medano Creek. The dunes cover approximately 40 square miles and rise as much as 700 feet above the valley floor. These photographs show the east part of the dune field and the lower slopes of the adjacent mountains. The sharp individual dune crests, and the many directions of their trends suggest variable winds.

Colo. 11. Radiating dikes on flanks of Silver Mountain

County: Huerfano.
Lat 37°37′ N.; long 105°04′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Date flown: Sept. 9, 1938.
Map reference: U.S. Geol. Survey Trinidad sheet, scale 1:250,000.
Geology reference: Johnson, R. B., 1961, Patterns and origin of radial dike swarms associated with West Spanish Peak and Dike Mountain, south-central Colorado: Geol. Soc. America Bull., v. 72, no. 4, p. 579–590; see fig. 3.

Features illustrated (set nos. Colo. 11 A–B in southeast corner of photographs).—Radial dike swarm on the northeast flank of Silver Mountain (Dike Mountain of Johnson; southwest corner of photograph 11 A). Trend of dikes ranges from east to west along the southern edge of area shown in photographs and from north to south along its western border. Dikes are discontinuous and form prominent ridges.

Colo. 12. Intersecting dikes northeast of Spanish Peaks

County: Huerfano.
Lat 37°30′ N.; long 104°51′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Sept. 17, 1938.
Map reference: U.S. Geol. Survey Trinidad sheet, scale 1:250,000.
Geology reference: Johnson, R. B., 1961, Patterns and origin of radial dike swarms associated with West Spanish Peak and Dike Mountain, south-central Colorado: Geol. Soc. America Bull., v. 72, no. 4, p. 579–590.

Features illustrated (set nos. Colo. 12 A–B in southeast corner of photographs).—A large east-trending dike (northern half of photograph 12 B) cuts across older radial dikes that trend in a southwesterly direction. The bedrock is mostly competent sedimentary rocks of late Paleozoic and Mesozoic ages. Dikes form prominent ridges that control the drainage pattern.

Conn. 1. Triassic basalt ridges and border fault near Middletown

County: Middlesex.
Lat 41°33′ N.; long 72°40′ W.
Number of photographs: 4.
Photograph scale: 1:60,000.
Focal length: 6 in.
Date flown: Oct. 29, 1959.
Map reference: U.S. Geol. Survey Meriden, Middletown, and Middle Haddam 7½-min quadrangles, scale 1:24,000.
Geology reference: Lehmann, E. P., 1959, The bedrock geology of the Middletown quadrangle: Connecticut Geol. and Nat. History Survey, Quad. Rept. 8, 40 p.; geol. map, scale 1:24,000.

Features illustrated (set nos. Conn. 1 A–D in northeast corner of photographs).—East-dipping Triassic basalt flows form wooded hills (eastern third of photograph 1 D) and are overlain by sedimentary rocks and minor basalt that extend east to a line about 2 miles east of Middletown on Connecticut River (east edge of photograph 1 C). The flooded building-stone quarries on the east bank of the river just north of the bridge are in arkose; they provided much of the brownstone used in New York City in the late 19th century. A conspicuous topographic break trending slightly east of north (west half of photograph 1 A) marks the trace of the fault between the Triassic rocks and the older gneisses and schists of the eastern highlands. Pegmatite quarries just east of the border fault show as white spots about 1½ inches southwest of the northeast corner of photograph 1 B. A drift-filled abandoned course of the Connecticut River, marked by a large kettle lake, trends north-northwest from the center of photograph 1 A.

Del. 1. Shoreline changes at Cape Henlopen

County: Sussex.
Lat 38°47′ N.; long 75°06′ W.
Number of photographs: 4.
Photograph scale: 1:20,000.
Focal length: 6 in.
Date flown: Aug. 14, 1954, Mar. 15, 1962.
Map reference: U.S. Geol. Survey Cape Henlopen 7½-min quadrangle, scale 1:24,000.

Features illustrated (set nos. Del. 1 A–B in southeast corner of 1954 photographs and set nos. Del. 1 C–D in northwest corner of 1962 photographs).—Cape Henlopen spit, at the mouth of Delaware Bay opposite Cape May, N.J., has grown northward more than a mile since the area was first surveyed about 200 years ago. During this interval, the shore west of the cape moved northward perhaps a quarter of a mile, and the Atlantic shore was cut back about the same amount. During the more than 7-year interval between the 1954 and the 1962 photographs, the tip of the spit grew northward about 500 feet and the sand dunes on the Atlantic shore have advanced westward across the adjacent roads and trails. The photographs provide only partial stereoscopic coverage (D. W. Moody, written commun., 1964).

Fla. 1. Beach ridges, St. Vincent Island

County: Franklin.
Lat 29°40′ N.; long 85°10′ W.
Number of photographs: 2.
Photograph scale: 1:43,100.
Focal length: 5.2 in.
Date flown: Nov. 1, 1942.
Map reference: U.S. Geol. Survey Indian Pass and West Pass 7½-min quadrangles, scale 1:24,000.

Features illustrated (set nos. Fla. 1 A–B in northeast corner of photographs).—The island is made up entirely of beach ridges and intervening marsh. It has grown southward about 4 miles, during the present sea-level stand. The pattern of ridges suggests that three erosional intervals interrupted the process of island growth (C. A. Kaye, written commun., 1961).

Fla. 2. Tidal marsh and cypress swamp at mouth of Suwannee River

County: Dixie and Levy.
Lat 29°18′ N.; long 83°09′ W.
Number of photographs: 3.
Photograph scale: 1:32,800.
Focal length: 5.2 in.
Date flown: Mar. 26, 1951.
Map reference: U.S. Geol. Survey Suwannee and East Pass 7½-min quadrangles, scale 1:24,000.

Features illustrated (set nos. Fla. 2 A–C in northeast corner of photographs).—The Suwannee River empties into the sea through several distributaries. The land along the shore is a tidal marsh that is generally 1–2 miles wide and is traversed by intricately meandering tidal estuaries. Slightly higher and drier ground is cypress swamp. Similar cypress swamp, bordered to seaward by tidal marsh, forms a belt 5–10 miles wide along the coast of northwest Florida. Altitudes are generally not more than 6 feet (C. A. Kaye, written commun., 1961).

Fla. 3. Shoreline changes at Lacosta Island, 1944–60

County: Lee.
Lat 26°41′ N.; long 82°16′ W.
Number of photographs: 4.
Photograph scale: 1:20,000, 1944; 1:28,000, 1951, 1960; 1:62,000, 1950.
Date flown: 1944, 1950, 1951, 1960.
Map reference: U.S. Geol. Survey Port Boca Grande and Bokeelia 7½-min quadrangles, scale 1:24,000.

Features illustrated (set nos. Fla. 1 A, 1 C, and 1 D in southeast corner of photographs; set no. Fla. 1 B in northeast corner of photograph).—The island (1950 photograph) consists of several sets of beach ridges with small areas of mangrove swamp on its east side. In 1960, sediment was carried out through a gap in the barrier islands (Boca Grande, northwest quadrant of same photograph) and built a curved bar west of the island on Big Shoal. Comparison of the 1944 and 1951 photographs shows that during this 7-year interval the cuspate foreland on the gulf side of the island was prograded and the bar on Big Shoal was modified. The 1960 photograph, taken 2 months after hurricane Donna hit the coast, shows that part of the bar had moved considerably nearer to the island. The cuspate foreland had been eroded and curves northward. This erosion suggests the movement of sediment in that direction during the hurricane (M. T. El-Ashry, written commun., 1963).

Ga. 1. Stone Mountain, a granitic dome

County: De Kalb.
Lat 33°48′ N.; long 84°09′ W.
Number of photographs: 2.
Photograph scale: 1:29,000.
Focal length: 6 in.
Date flown: Mar 9, 1955.
Map reference: U.S. Geol. Survey Stone Mountain 7½-min quadrangle, scale 1:24,000.
Geology reference: Hopson, C. A., 1958, Exfoliation and weathering at Stone Mountain, Georgia, and their bearing on disfiguration of the Confederate monument: Georgia Mineral Newsletter, v. 11, no. 3, p. 65–79.

Features illustrated (set nos. Ga. 1 A–B in southeast corner of photographs).—This prominent granitic dome (muscovite-quartz monzonite) rises nearly 800 feet above the rolling Georgia piedmont. The dome is largely bare rock and no joints are visible. The rock has been quarried at the base of its south and east slopes. The Confederate Memorial on its north side is in shadow. The fact that the sheeting in the quartz monzonite, which cannot be seen in these photographs, conforms closely to the topography indicates that sheeting is caused by relief of primary confining pressure during unloading because of erosion.

Hawaii 1. Topographic contrasts on Kohala Mountain

County: Hawaii.
Lat 20°05′ N.; long 155°43′ W.
Number of photographs: 6.
Photograph scale: 1:45,000.
Focal length: 6 in.
Date flown: Oct. 14, 1944.
Map reference: U.S. Geol. Survey Honokane and Kamuela 7½-min quadrangles, scale 1:24,000.
Geology reference: Stearns, H. T., and Macdonald, G. A., 1946, Geology and ground-water resources of the Island of Hawaii: Hawaii Div. Hydrography Bull. 9, 363 p.; geol. map (pl. 1), scale 1:125,000.

Features illustrated (set nos. Hawaii 1 A–F in northwest corner of photographs).—This strip of six photographs extends from the wet northeast slope of Kohala Mountain, a 6,000-foot volcano, to its dry southwest slope. Just northeast of the summit on the windward side, the rainfall exceeds 400 inches a year, the slopes are heavily forested, and deep precipitous canyons extend to the coast. On the lee side of the crest the rainfall drops abruptly to less than 100 inches per year and decreases to less than 50 inches farther down the southwestern slope where the forest is absent and the small ephemeral streams are only slightly incised. Cinder cones mark the mountain crest.

Hawaii 2. Lava terrain on dry west coast of Island of Hawaii

County: Hawaii.
Lat 19°48′ N.; long 156°00′ W.
Number of photographs: 3.
Photograph scale: 1:42,000.
Focal length: 6 in.
Date flown: Oct. 1, 1954.
Map reference: U.S. Geol. Survey Makalawena and Kiholo 7½-min quadrangles, scale 1:24,000.
Geology reference: Wentworth, C. K., and Macdonald, G. A., 1953, Structures and forms of basaltic rocks in Hawaii: U.S. Geol. Survey Bull. 994, 98 p.

Features illustrated (set nos. Hawaii 2 A–C in southeast corner of photographs).—Flowing basaltic lava is usually concentrated into one or two main streams. Under certain conditions, fluid lava beneath the crusted surface may drain away and convert the channel into a tube. The course of such a tube in the southeast quadrant of photograph 2 B is marked by a line of holes through the roof. Aa lava, such as the Kaupulehu flow of 1801, is rough and rubbly, and it photographs dark. The surface of pahoehoe lava is continuous, though perhaps hummocky; it photographs light, although the rock itself is the same color as that in the aa flow.

The older flows support more vegetation than the younger flows in the same climatic zone. A single flow may be bare of vegetation in zones of low rainfall and densely covered in zones of high rainfall (southeast quadrant of photograph 2 A).

A sea cliff is cut on the 1801 flow as well as on older prehistoric flows.

Hawaii 3. East slope of Mauna Kea north of Wailuku River

County: Hawaii.
Lat 19°46′ N.; long 155°13′ W.
Number of photographs: 2.
Photograph scale: 1:44,200.
Focal length: 6 in.
Date flown: Oct. 14, 1954.
Map reference: U.S. Geol. Survey Piihonua 7½-min quadrangle, scale 1:24,000, and Honomu 15-min quadrangle, scale 1:62,500.
Geology reference: Stearns, H. T., and Macdonald, G. A., 1946, Geology and ground-water resources of the Island of Hawaii: Hawaii Div. Hydrography Bull. 9, 363 p.; geol. map (pl. 1), scale 1:125,000.

Features illustrated (set nos. Hawaii 3 A–B in northwest corner of photographs).—The eastern slope of Mauna Kea at altitudes from about 2,500 to 3,000 feet where rainfall ranges from 250 to 300 inches a year. The slope of the volcano has a well-integrated drainage system developed in Pahala Ash overlying basalt lava.

Hawaii 4. Coastal margin of Mauna Kea north of Hilo

County: Hawaii.
Lat 19°46′ N.; long 155°06′ W.
Number of photographs: 2.
Photograph scale: 1:45,000.
Focal length: 6 in.
Date flown: Oct. 14, 1954.
Map reference: U.S. Geol. Survey Hilo and Piihonua 7½-min quadrangles, scale 1:24,000, and Honomu 15-min quadrangle, scale 1:62,500.

Geology reference: Stearns, H. T., and Macdonald, G. A., 1946, Geology and ground-water resources of the Island of Hawaii: Hawaii Div. Hydrography Bull. 9, 363 p.; geol. map (pl. 1,) scale 1:125,000.

Features illustrated (set nos. Hawaii 4 A–B in northwest corner of photographs).—The eastern slope of Mauna Kea along the coast where rainfall ranges from 150 to 200 inches a year. Near the coast are many deep and steep-sided meandering canyons and a sea cliff, both carved in the Pahala Ash that overlies basalt. The sea cliff is about 100 feet high.

Hawaii 5. The undissected east slope of Mauna Loa near terminus of 1942 flow

County: Hawaii.
Lat 19°38′ N.; long 155°13′ W.
Number of photographs: 2.
Photograph scale: 1:44,200.
Focal length: 6 in.
Date flown: Oct. 14, 1954.
Map reference: U.S. Geol. Survey Piihonua and Puu Makaala 7½-min quadrangles, scale 1:24,000
Geology reference: Stearns, H. T., and Macdonald, G. A., 1946, Geology and ground-water resources of the Island of Hawaii: Hawaii Div. Hydrography Bull. 9, 363 p.; geol. map (pl. 1), scale 1:125,000.

Features illustrated (set nos. Hawaii 5 A–B in northwest corner of photographs).—The northeast slope of Mauna Loa at an altitude of 2,500–3,000 feet where rainfall ranges from 250 to 300 inches a year. The slope is mainly undissected. The rock is basalt. The terminus of the 1942 lava flow and of an older 1852 flow to the north are in the northwest quadrant of photograph 5 A.

Hawaii 6. Coastal margin of Manna Loa south of Hilo

County: Hawaii.
Lat 19°41′ N.; long 155°01′ W.
Number of photographs: 2.
Photograph scale: 1:43,000.
Focal length: 6 in.
Date flown: Nov. 12, 1954.
Map reference: U.S. Geol. Survey Hilo and Keaau Ranch 7½-min quadrangles, scale 1:24,000.
Geology reference: Stearns, H. T., and Macdonald, G. A., 1946, Geology and ground-water resources of the Island of Hawaii: Hawaii Div. Hydrography Bull. 9, 363 p.; geol. map (pl. 1), scale 1:125,000.

Features illustrated (set nos. Hawaii 6 A–B in northwest corner of photographs).—The east slope of Mauna Loa near the coast where rainfall ranges from 150 to 200 inches a year. The east slope of the volcano lacks stream channels, and the coastline is smooth. The rock is basalt lava.

Hawaii 7. Fissure eruptions from southwest rift zone, Mauna Loa

County: Hawaii.
Lat 19°18′ N.; long 155°43′ W.
Number of photographs: 3.
Photograph scale: 1:41,200.
Focal length: 6 in.
Date flown: Oct. 1, 1954.
Map reference: U.S. Geol. Survey Mauna Loa and Honaunau 15-min quadrangles, scale 1:62,500.
Geology reference: Stearns, H. T., and Macdonald, G. A., 1946, Geology and ground-water resources of the Island of Hawaii: Hawaii Div. Hydrography Bull. 9, 363 p.; geol. map (pl. 1), scale 1:125,000. Finch, R. H., and Macdonald, G. A., 1953, Hawaiian volcanoes during 1950: U.S. Geol. Survey Bull. 996–B, 89 p.; geol. map (pl. 1), scale 1:190,000.

Features illustrated (set nos. Hawaii 7 A–C in southeast corner of photographs).—Hawaiian eruptions of basaltic lava commence with copious emission of gas-charged lava from long fissures or rifts. Several undated rift eruptions and parts of several historic eruptions came from the southwest rift zone of Mauna Loa that passes through the center of photograph 7 B. In the southwest quadrant, a row of 1919 cinder cones are west of the main rift zone and south of a line of pits (black dots in white area) that marks a lava tube. A line of black spatter cones on the main rift zone south of the 1919 cones marks the 1926 rift and associated lavas. The 1950 rift (black line in northeast quadrant) produced lava rivers that flowed westward. The 1950 flows are not shown on the topographic map which was surveyed in 1926. It is difficult to identify the ages of all the flows shown in these photographs without reference to plate 1 of Stearns and Macdonald and plate 1 of Finch and Macdonald.

Hawaii 8. Kilauea Caldera

County: Hawaii.
Lat 19°25′ N.; long 155°17′ W.
Number of photographs: 3.
Photograph scale: 1:35,000.
Focal length: 6 in.
Date flown: Oct. 14, Nov. 1, 1954.
Map reference: U.S. Geol. Survey Kilauea 15-min quadrangle, scale 1:62,500.
Geology reference: Macdonald, G. A., and Eaton, J. P., 1957, Hawaiian volcanoes during 1954: U.S. Geol. Survey Bull. 1061–B, p. 17–72; pl. 1, scale 1:24,000. Macdonald, G. A., and Hubbard, D. H., 1961, Volcanoes of the national parks in Hawaii [2d ed.]: Hawaii Nat. History Assoc., 41 p.; fig. 4, scale 1:62,500.

Features illustrated (set nos. Hawaii 8 A–C in southeast corner of photographs).—The summit caldera of Kilauea Volcano is bordered by fault scarps and floored by lava flows erupted within the last century. Along the western and northern edges are step faults. Near the southwest edge of the caldera floor is the "Fire Pit" Halemaumau, a crater about 500-feet deep that is the focus of Kilauea's eruptive activity. In these photographs the spatter cone of the 1952 eruption stands above the floor of Halemaumau, which is covered with lava formed in 1952 and 1954. A fissure that extends east-northeast from the northeast side of the crater fed the 1954 lava flow, whose dark color on the aerial photographs contrasts with the surrounding lighter colored weathered flows. Open fissures that extend southwest from Halemaumau are the surface expression of the north end of the southwest rift of Kilauea. Oblique view is northward; Mauna Kea is in the background.

Hawaii 9. Pit craters and lava lakes on flank of Kilauea Volcano

County: Hawaii.
Lat 19°22′ N.; long 155°09′ W.
Number of photographs: 2.
Photograph scale: 1:44,000.
Focal length: 6 in.
Date flown: Oct. 14, 1954.
Map reference: U.S. Geol. Survey Puna 15-min quadrangle, scale 1:62,500.
Geology reference: Stearns, H. T., and Macdonald, G. A., 1946, Geology and ground-water resources of the Island of Hawaii: Hawaii Div. Hydrography Bull. 9, 363 p.; geol. map (pl. 1), scale 1:125,000.

Features illustrated (set nos. Hawaii 9 A–B in southeast corner of photographs.)—The features visible on the photographs are as follows, listed from oldest to youngest: Flow of lava from forest-covered dome; summit of crater, Kane Nuio Hamo, near the center of northwest quadrant of photograph 9 A. Collapse of earliest Makaopuhi pit crater just south of dome. Lava from fissures forming an east-west-trending flow just north of pit craters; now covered by a dense single-species forest. Collapse of Napau pit crater (northeast quadrant of photograph 9 A). Another flow from fissures and into the Napau crater to form a lava lake now partly forested. Flow from area to the west covers the west edge of photograph 9 A and ends along the curved forest border that passes around the west edge of Makaopuhi pit crater; this flow also formed a lava lake in this pit that has since collapsed.

Hawaii 10. Flank eruptions near Kapoho, 1955 and 1960

County: Hawaii.
Lat 19°30′ N.; long 154°51′ W.
Number of photographs: 4.
Photograph scale: 1:43,000, 1954; 1:40,000, 1961.
Focal length: 6 in.
Date flown: Nov. 12, 1954, Feb. 4, 1961.
Map reference: U.S. Geol. Survey Makuu and Kalapana 15-min quadrangles, scale 1:62,500.
Geology reference: Macdonald, G. A., and Eaton, J. P., 1964, Hawaiian volcanoes during 1955: U.S. Geol. Survey Bull. 1171, 170 p.; map (pl. 1), scale 1:62,500. Richter, D. H., and Eaton, J. P., 1960, The 1959–60 eruption of Kilauea Volcano: New Scientist, v. 7, p. 994–997. Macdonald, G. A., 1962, The 1959–60 eruption of Kilauea Volcano, Hawaii, and the construction of walls to restrict the spread of lava flows: Bull. Volcanol. v. 24, p. 249–294; map (fig. 2).

Features illustrated (set nos. Hawaii 10 A–B in northwest corner).—The 1954 photographs show that the Kapoho-Cape Kumukahi region is an area of sugarcane fields and forest land. The town of Kapoho nestles on the north side of the prehistoric cone Kapoho on the edge of a shallow northeast-trending graben.

The 1961 photographs (*set nos. Hawaii 10 C–D in southeast corner*) show the same area ravaged by two flank eruptions of Kilauea Volcano. Between March 1 and 6, 1955, 36 million cubic yards of lava and cinders were erupted from vents west of the Kapoho cone (near center of west edge of photograph 10 D). This lava forms the Kii flow which covered 1,100 acres south of Kapoho (the dark area that extends east-west just south of cone). Between January 13 and February 20, 1960, 156 million cubic yards of lava were extruded from vents north and east of Kapoho; the lava covered 2,000 acres of land (in northeast quadrant of same photograph) and formed 500 acres of new land beyond the former coastline.

Idaho 1. Sand dunes on floor of Eagle Cove south of Snake River

County: Owyhee.
Lat 42°53′ N.; long 115°42′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: July 24, 1957.
Map reference: U.S. Geol. Survey Sand Dunes 7½-min quadrangle, scale 1:24,000.
Geology reference: Malde, H. E., Powers, H. A., and Marshall, C. H., 1963, Reconnaissance geologic map of west-central Snake River Plain, Idaho: U.S. Geol. Survey Misc. Geol. Inv. Map I–373.

Features illustrated (set nos. Idaho 1 A–B in southeast corner of photographs).—The most prominent feature of this small dune field is an irregular hill of bare sand, more than 450 feet high and about a mile long. The dunes rest on the flat floor of the cove, which is 2–3 miles across and is an embayment in the cliffs on the south side of the Snake River between Hammett and Bruneau. The sand comes from the flat upland surface west of the cove and about 350 feet above its floor.

Idaho 2. Patterns of mounds and stripes near Glenns Ferry

County: Elmore.
Lat 43°03′ N.; long 115°11′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Oct. 22, 1950.
Map reference: U.S. Geol. Survey King Hill 15-min quadrangle, scale 1:62,500.
Geology reference: Malde, H. E., 1964, Patterned ground in the western Snake River Plain, Idaho, and its possible cold-climate origin: Geol. Soc. America Bull., v. 75, p. 191–208; see pl. 1, fig. 1. Malde, H. E., Powers, H. A., and Marshall, C. H.,

1963, Reconnaissance geologic map of west-central Snake River Plain, Idaho: U.S. Geol. Survey Misc. Geol. Inv. Map I–373.

Features illustrated (set nos. Idaho 2 A–B in southeast corner of photographs).—A plateau of weathered basalt, smoothed by mass wasting, is marked by closely packed circular mounds of silt about 50 feet in diameter. These mounds are surrounded by a dark pavement of basalt rubble. An apron of basaltic colluvium along the southeast margin of the plateau is also marked with mounds, but these lie along downhill stripes of soil that alternate with stripes of rubble. The pattern of mounds, pavement, and stripes probably is a relict of a former periglacial climate. (Idaho 2 and 3 overlap.)

Idaho 3. Earthflow near King Hill

County: Elmore.
Lat 43°02′ N.; long 115°14′ W.
Number of photographs: 3.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Oct. 22, 1950.
Map reference: U.S. Geol. Survey King Hill 15-min quadrangle, scale 1:62,500.
Geology reference: Malde, H. E., Powers, H. A., and Marshall, C. H., 1963, Reconnaissance geologic map of west-central Snake River Plain, Idaho: U.S. Geol. Survey Misc. Geol. Inv. Map I–373.

Features illustrated (set nos. Idaho 3 A–C in southeast corner of photographs).—An earthflow covering about 2 square miles lies immediately north of King Hill in the southwest quadrant of photograph 3 B. It descended 1,000 feet to King Hill Creek, a tributary of the Snake River, and came to rest on unconsolidated sand and gravel that had been previously deposited by catastrophic outflow from Pleistocene Lake Bonneville. Well-defined slump blocks, still capped by basalt, are conspicuous features in the upper part of this landslide. Patterned ground is visible on top of the basalt mesa. (Idaho 2 and 3 overlap.)

Idaho. 4. Gravel bars and scabland near King Hill

County: Elmore.
Lat 42°58′ N.; long 115°11′ W.
Number of photographs: 3.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Oct. 22, 1950.
Map reference: U.S. Geol. Survey Pasadena Valley 7½-min quadrangle, scale 1:24,000.
Geology reference: Malde, H. E., Powers, H. A., and Marshall, C. H., 1963, Reconnaissance geologic map of west-central Snake River Plain, Idaho: U.S. Geol. Survey Misc. Geol. Inv. Map I–373. Malde, H. E., 1960, Evidence in the Snake River Plain, Idaho, of a catastrophic flood from Pleistocene Lake Bonneville, *in* Short papers in the geological sciences: U.S. Geol. Survey Prof. Paper 400–B, p. B295–B297.

Features illustrated (set nos. Idaho 4 A–C in southeast corner of photographs).—The surface of a basalt flow between Snake River and the railroad (east part of photograph 4 B) has potholes and other scour features caused by passage of a gigantic flood when Pleistocene Lake Bonneville overflowed into Snake River near Preston. Farther downstream (The Pasture, northeast quadrant of same photograph), streamlined bars of basaltic gravel overlie the basalt. West of the river, in the southern part of photograph 4 B, enormous bars of boulder gravel form a high bench separated from the west wall of the canyon by a marginal channel—Pasadena Valley—floored with fine-grained deposits.

Idaho 5. Rift zone, Craters of the Moon

County: Butte.
Lat 43°27′ N.; long 113°34′ W.
Number of photographs: 3.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: July 23, 1959.
Map reference: U.S. Geol. Survey Craters of the Moon National Monument, Idaho, scale 1:31,680.
Geology reference: Stearns, H. T., Crandall, Lynn, and Steward, W. G., 1938, Geology and ground-water resources of the Snake River Plain in southeastern Idaho: U.S. Geol. Survey Water-Supply Paper 774, 268 p.; geol. map (pl. 13), scale 1:47,500.

Features illustrated (set nos. Idaho 5 A–C in southeast corner of photographs).—Basaltic cinder cones, many of which are alined along a northwest-trending rift zone, have conspicuous craters of various sizes. In places the rift zone is marked by a line of small spatter cones (near center of photograph 5 B). The craters are surrounded by dark-toned basalt flows that issued from the rift zone. Older basalt flows, in part covered by vegetation, are in the north half of photograph 5 A.

Idaho 6. Patterned alluvial fans near Mackay

County: Custer and Butte.
Lat 43°47′ N.; long 113°29′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Aug. 1, 1946.
Map reference: U.S. Geol. Survey Idaho Falls sheet, scale 1:250,000.
Geology reference: Malde, H. E., 1964, Patterned ground in the western Snake River Plain, Idaho: Geol. Soc. America Bull., v. 75, no. 3, p. 191–208.

Features illustrated (set nos. Idaho 6 A–B in southeast corner of photographs).—Dissected gravel fans that border the Big Lost River valley near Mackay are marked with a distinct pattern of silt mounds that may represent the effects of a former periglacial climate. Similar features are described by Malde (1964).

Idaho 7. Menan Buttes

County: Madison.
Lat 43°47′ N.; long 111°58′ W.
Number of photographs: 3.
Photograph scale: 1:25,000.
Focal length: 6 in.
Date flown: Oct. 8, 1950.
Map reference: U.S. Geol. Survey Menan Buttes 7½-min quadrangle, scale 1:24,000.
Geology reference: Hamilton, Warren, and Myers, W. B., 1963, Menan Buttes, cones of glassy basalt tuff in the Snake River Plain, Idaho, *in* Short papers in geology, hydrology, and topography: U.S. Geol. Survey Prof. Paper 450–E, p. E114–E118.

Features illustrated (set nos. Idaho 7 A–C in southeast corner of photographs).—The Menan Buttes are two cones of basalt tuff that rise from a surface of Recent basalt flows on the Snake River Plain 20 miles north of Idaho Falls. Asymmetry of the Menan Buttes demonstrates northeastward drift of pyroclastic ejecta parallel to the prevailing winds. The cones were built by small fragments of solid glass that were erupted explosively within the craters and then fell to form the inner walls of the craters as well as the outer slopes of the cones. The meandering channel of Snake River and its wooded flood plain are also well shown on these photographs.

Ill. 1. Hicks Dome

County: Hardin.
Lat 37°32′ N.; long 88°23′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: July 12, 1952.
Map reference: U.S. Geol. Survey Karbers Ridge and Herod 7½-min quadrangles, scale 1:24,000.
Geology reference: Snyder, F. G., and Gerdemann, P. E., 1965, Explosive igneous activity along an Illinois-Missouri-Kansas axis: Am. Jour. Sci., v. 263, p. 465–493; geol. map (fig. 2), scale 1:186,500.

Features illustrated (set nos. Ill. 1 A–B in southeast corner of photographs).—Hicks Dome, a low wooded limestone hill, is surrounded by an oval-shaped shale valley about 2 miles in longest diameter. These Devonian limestones include several explosion breccias or diatremes (not visible on photographs). A collar of wooded hills carved in outward-dipping Pennsylvanian sedimentary rocks surrounds the valley.

Ind. 1. Indiana sand dunes

County: Porter.
Lat 41°39′ N.; long 87°04′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: July 8, 1954.
Map reference: U.S. Geol. Survey Dune Acres 7½-min quadrangle, scale 1:24,000.
Geology reference: Cressey, G. B., 1928, The Indiana sand dunes and shorelines of the Lake Michigan basin: Geog. Soc. Chicago Bull. 8, 80 p.

Features illustrated (set nos. Ind. 1 A–B in southeast corner of photographs).—A belt of dunes about half a mile wide lies along the shore of Lake Michigan, between the beach and the marsh that separates the dunes from an older beach and dune ridge that is closely followed by highway and railroad. The dunes rise as much as 180 feet above the lake; in places a foredune—a discontinuous ridge—is adjacent to and parallel with the beach. The dunes on the shore are forested except for blowouts or great tongues of bare sand that project inland.

Ind. 2. Point bar on Ohio River flood plain near Henderson

County: Vanderburgh and Henderson.
Lat 37°52′ N.; long 87°38′ W.
Number of photographs: 4.
Photograph scale: 1:28,400.
Focal length: 6 in.
Date flown: Apr. 16, 1950.
Map reference: U.S. Geol. Survey Wilson, Henderson, West Franklin, and Evansville 7½-min quadrangles, scale 1:24,000.

Features illustrated (set nos. Ind. 2 A–D in northeast corner of photographs).—In the photographs, the meandering Ohio River flows from right to left. The entire area is covered by river alluvium except for loess-mantled hills in the northeast corner of photograph 2 D and except for dune sand along the river under the city of Henderson. The flood plain on the right bank of the river is a large point bar with two distinct patterns of low swell and swale topography. Configuration of the swells and swales in the central and east part of the point bar indicates a lateral southward movement of the river. Bedrock at Henderson has now deflected the river, and lateral cutting and building of the point bar, which have been concentrated on the southwest side, have formed a series of swells and swales at variance with the earlier ones. (L. L. Ray, written commun., 1965).

Iowa 1. Topographic discontinuities of the Des Moines lobe

County: Buena Vista.
Lat 42°38′ N.; long 95°12′ W.
Number of photographs: 3.
Photograph scale: 1:70,000.
Focal length: 6 in.
Date flown: Sept. 23, 1950.
Map reference: U.S. Geol. Survey Fort Dodge sheet, scale 1:250,000.
Geology reference: Ruhe, R. V., 1952, Topographic discontinuities of the Des Moines lobe: Am. Jour. Sci., v. 250, p. 46–56, fig. 2.

Features illustrated (set nos. Iowa 1 A–C in northeast corner of photographs).—Cultivated fields on poorly drained Cary drift (north half of photograph 1 B) have a mottled appearance that is lacking on the better drained Tazewell drift (south half of photograph 1 A) where the individual fields appear sharp and clear. The contact between the two drifts closely follows the railroad that runs northward from the south edge of the photographs to encircle Storm Lake and continue on in a northwest direction. There is also a difference in degree of integration of drainage between the area mantled by Tazewell drift and that mantled by Cary drift. The Tazewell surface has a high drainage density compared with that of the Cary drift. This contrast is, however, not obvious on these photographs.

Iowa 2. Paha in Benton County

County: Benton.
Lat 42°11′ N.; long 92°14′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Sept. 14, 1963.
Map reference: U.S. Geol. Survey Waterloo sheet, scale 1:250,000.
Geology reference: Scholtes, W. H., 1955, Properties and classification of the paha loess-derived soils in northeastern Iowa: Iowa State Coll. Jour. Sci., v. 30, no. 2, p. 163–209.

Features illustrated (set nos. Iowa 2 A–B in southeast corner of photographs).—According to Scholtes (see his fig. 6), two northwest-trending ridges, or paha, are in the southeast quadrant of photograph 2 A. The wooded area is an irregularly shaped paha, and a second cultivated ridge is just north of the woods, largely between the railroad and the section-line road that almost exactly bisects the north and south halves of the same photograph. The northern paha is covered with loess except for two small outcrops of Kansan till. The plain around the paha is Iowan drift with patches of loess.

Iowa 3. Paha near Vinton

County: Benton.
Lat 42°11′ N.; long 92°10′ W.
Number of photographs: 3.
Photograph scale: 1:70,000.
Focal length: 6 in.
Date flown: Oct. 18, 1950.
Map reference: U.S. Geol. Survey Waterloo sheet, scale 1:250,000.
Geology reference: Scholtes, W. H., 1955, Properties and classification of the paha loess-derived soils in northeastern Iowa: Iowa State Coll. Jour. Sci., v. 30, no. 2, p. 163–209; see fig. 3.

Features illustrated (set nos. Iowa 3 A–C in northeast corner of photographs).—A group of loess-covered ridges that have a pronounced northwest trend, are on the Iowan drift plain just west of Vinton on Cedar River (near the center of photograph 3 C) and are shown in figure 3 of Scholtes' paper. (Iowa 2 covers area in southwest quadrant of Iowa 3 A.)

Kans. 1. Changes in channel of Cimarron River near Rolla, 1936–60

County: Morton.
Lat 37°13′ N.; long 101°38′ W.
Number of photographs: 6.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Aug. 23, 1936, and June 29, 1960.
Map reference: U.S. Geol. Survey Dodge City sheet, scale 1:250,000.
Geology reference: Schumm, S. A., and Lichty, R. W., 1963, Channel widening and flood-plain construction along Cimarron River in southwestern Kansas: U.S. Geol. Survey Prof. Paper 352-D, p. 71–88, fig. 48A.

Features illustrated (set nos. Kans. 1 A–F in southeast corner of photographs).—These two triplets show a narrowing of the channel and a growth of vegetation on the flood plain along the Cimarron River north of Rolla, Kans., that took place between 1936 and 1960. West of the bridge along State Route 51, the channel had an average width of about 2,500 feet in 1936 and of about 800 feet in 1960. This change occurred during a period of above-average annual precipitation and floods of low to moderate peak discharge. Vegetation became established in the wide sandy channel and aided deposition and flood-plain formation.

Kans. 2. Flat-lying limestone and shale in the Flint Hills

County: Pottawatomie.
Lat 39°17′ N.; long 96°33′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Sept. 18, 1937.
Map reference: U.S. Geol. Survey Manhattan sheet, scale 1:250,000.
Geology reference: Scott, G. R., Foster, F. W., Crumpton, C. F., 1959, Geology and constructional material resources of Pottawatomie County, Kansas: U.S. Geol. Survey Bull. 1060-C, p. 97–178; geol. map (pl. 2), scale 1:62,500.

Features illustrated (set nos. Kans. 2 A–B in southeast corner of photographs).—Flat-lying cherty limestone and shale of Permian age in northeast Kansas. The white bands are outcrops of limestone; the wider gray bands are intervening beds of shale. Area is prairie; trees grow only in valleys on the banks of Cedar Creek and its tributaries that are incised below the Flint Hills Upland.

Ky. 1. Sand Ridge at Flaherty

County: Meade and Hardin.
Lat 37°49′ N.; long 86°04′ W.
Number of photographs: 3
Photograph scale: 1:24,000.
Focal length: 6 in.
Date flown: Jan. 25, 1960.
Map reference: U.S. Geol. Survey Flaherty 7½-min quadrangle, scale 1:24,000.

Geology reference: Swadley, W. C., 1963, Geology of the Flaherty quadrangle, Kentucky: U.S. Geol. Survey Geol. Quad. Map. GQ-229.

Features illustrated (set nos. Ky. 1 A–C in southeast corner of photographs).—The sandstone member of the Mooretown Formation (Mississippian) was deposited in a large channel cut deeply into the underlying Ste. Genevieve Limestone and St. Louis Limestone. Erosion has transformed the sandstone member into Sand Ridge, which south of Flaherty is largely wooded. East of the town, the ridge is less prominent and largely bare of trees. The low rolling hills and flats with numerous broad shallow sinkholes west of the longitude of Flaherty are on the Ste. Genevieve Limestone. East of the line, the underlying St. Louis Limestone is marked by many small and deep sinks, except for a very broad sink (or valley) floored with alluvium near the center of photograph 1 A.

Ky. 2. Sinkholes in cherty limestone near Bristow

County: Warren.
Lat 37°02′ N.; long 86°16′ W.
Number of photographs: 2.
Photograph scale: 1:18,000.
Focal length: 6 in.
Date flown: Feb. 12, 1954.
Map reference: U.S. Geol. Survey Bristow 7½-min quadrangle, scale 1:24,000.
Geology reference: Gildersleeve, Benjamin, 1963, Geology of the Bristow quadrangle, Kentucky: U.S. Geol. Survey Geol. Quad. Map GQ-216.

Features illustrated (set nos. Ky. 2 A–B in northeast corner of photographs).—Broad and shallow sinkholes in the north half of photograph 2 A have been formed in the Ste. Genevieve Limestone. The smaller deeper more steep sided and more abundant sinkholes in the southern half of the exposure are in St. Louis Limestone. Outcrops are scarce. The Ste. Genevieve Limestone, largely concealed beneath a weathered residuum containing chert blocks as much as 2 feet in maximum diameter, is a thick-bedded and oolitic limestone interbedded with nonoolitic lithographic to coarse-grained limestone. The St. Louis Limestone, covered in most places by a thick residuum of clay containing abundant chert nodules, is a cherty lithographic to coarse-grained thin- to medium-bedded limestone.

Ky. 3. Cedar Sink

County: Edmonson.
Lat 37°10′ N.; long 86°10′ W.
Number of photographs: 3.
Photograph scale: 1:23,600.
Focal length: 6 in.
Date flown: Mar. 19, 1953.
Map reference: U.S. Geol. Survey Rhoda 7½-min quadrangle, scale 1:24,000.
Geology reference: Klemic, Harry, 1963, Geology of the Rhoda quadrangle, Kentucky: U.S. Geol. Survey Geol. Quad. Map GQ-219.

Features illustrated (set nos. Ky. 3 A–C in northeast corner of photographs).—The narrow flood plain of the meandering Green River is carved in virtually flat-lying Upper Mississippian limestones (Girkin Formation and Ste. Genevieve Limestone). The upper walls of Green River valley are composed of thick beds of sandstone with interbedded limestone. A stream heading in the southwest corner of photograph 3 B flows northeastward for about 2 miles to end in a sinkhole about half a mile from Green River and at about the same altitude. In the southeast quadrant of the same photograph, another large valley with gently sloping sides (Smith Valley) and no surface drainage contains a small steep-sided deep sinkhole (Cedar Sink) whose floor is also at about the same altitude as Green River.

Ky. 4. Karst near Park City

County: Edmonson and Barren.
Lat 37°06′ N.; long 86°05′ W.
Number of photographs: 2.
Photograph scale: 1:18,000.
Focal length: 6 in.
Date flown: Feb. 22, 1954.
Map reference: U.S. Geol. Survey Park City 7½-min quadrangle, scale 1:24,000.
Geology reference: Haynes, D. D., 1962, Geology of the Park City quadrangle, Kentucky: U.S. Geol. Survey Geol. Quad. Map GQ-183.

Features illustrated (set nos. Ky. 4 A–B in northeast corner of photographs).—In the southern half of the photographs, the St. Louis Limestone underlies a well-developed karst area consisting of abundant small closely spaced and deep sinkholes. The larger shallower and less abundant sinks to the north are in the overlying Ste. Genevieve Limestone. The wooded hills have sandstone caps (Big Clifty Sandstone Member of Golconda Formation).

La. 1. Poverty Point archaeologic site on terrace along Bayou Macon

County: West Carroll and East Carroll Parishes.
Lat 32°38′ N.; long 91°24′ W.
Number of photographs: 3.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Nov. 11, 1960.
Map reference: U.S. Geol. Survey Mitchiner 15-min quadrangle, scale 1:62,500.
Geology reference: Fisk, H. N., 1944, Geological investigations of the alluvial valley of the lower Mississippi River: Vicksburg, Miss., Mississippi River Comm., 78 p.; see pl. 15, sheet 3, scale 1:250,000. Ford, J. A., and Webb, C. H., 1956, Poverty Point, a late Archaic site in Louisiana: Am. Mus. Nat. History Anthropol. Papers, v. 46, pt. 1, 136 p.

Features illustrated (set nos. La. 1 A–C in southeast corner of photographs).—The Poverty Point archaeologic site is on a flat terrace separated by a 15-foot bluff from Bayou Macon to the east. The most prominent topographic feature at the site is an artificial mound more than 50 feet high, but the most conspicuous pattern on these photographs are six concentric artificial earth ridges that form about half of a large octagon (northwest quadrant of photograph 1 B. The site lies on the edge of a flat plain that is a remnant of an alluvial fan of the Arkansas River (Fisk's stage A–1). The plain east of the bayou about 15 feet below the fan's surface is the remnant of a younger flood plain cut by the Arkansas River (Fisk's stage H). Joes Bayou (east edge of photographs 1 B and 1 C) is the trace of a still younger, meandering channel of the river (Fisk's stage 1). The archaeologists believe that the bluff along Bayou Macon was cut after the earthworks were constructed. This cut erased half of what may have once been a complete octagonal figure. Thus the earthworks were made prior to stage H. Fisk estimated the age of stage H as from 2,000 to 3,000 years. Radiocarbon age determinations suggest that the cultural levels at the Poverty Point site are from 2,550 to 2,750 years old.

La. 2. Point bars and natural levees along Walnut Bayou

County: Madison Parish.
Lat 32°20′ N.; long 91°06′ W.
Number of photographs: 3.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: May 17, 1956.
Map reference: U.S. Geol. Survey Talla Bena 15-min quadrangle, scale 1:62,500.
Geology reference: Fisk, H. N., 1944, Geological investigations of the alluvial valley of the lower Mississippi River: Vicksburg, Miss., Mississippi River Comm., 78 p.; see pl. 22, sheet 11, scale 1:62,500.

Features illustrated (set nos. La. 2 A–C in southeast corner of photographs).—Walnut Bayou, bordered by natural levees, runs northwest across northeast quadrant of photograph 2 B and is a segment of an ancient meandering channel or point bar of the Mississippi River (stage 11 of Fisk). Scrolls related to slightly older channels are visible northeast of the bayou (stages 9 and 10). Faint scrolls of still older channels (stages 5–7) trend north-northeast in northwest quadrant of photograph 2 B.

The wooded Indian mounds in fields just southwest of the bayou (east of center of photograph 2 B) are the Fitzhugh archaeologic site; this site must be younger than Fisk's stage 11, which he estimates at perhaps not more than 1,000 years old.

La. 3. Chenier plain and Calcasieu Pass at Cameron

County: Cameron Parish.
Lat 29°47′ N.; long 93°20′ W.
Number of photographs: 3.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Apr. 5, 1957.
Map reference: U.S. Geol. Survey Cameron 7½-min quadrangle, scale 1:24,000.
Geology reference: Byrne, T. V., LeRoy, D. O., Riley, C. M., 1959, The Chenier Plain and its stratigraphy, southwestern Louisiana: Gulf Coast Assoc. Geol. Soc. Trans., v. 9, p. 237–260. Gould, H. R., and McFarlan, E., Jr., 1959, Geologic history of the Chenier Plain, southwestern Louisiana: Gulf Coast Assoc. Geol. Soc. Trans., v. 9, p. 261–270.

Features illustrated (set nos. La. 3 A–C in southeast corner of photographs).—These curving beach ridges or cheniers record progressive changes in the configuration of the shoreline as it advanced seaward during the last 3,000 years. The cheniers are lenticular sand and shell bodies, averaging about 300 feet across, as much as 7 feet thick, and as much as 30 miles long, that rest on finer sediment and are overlapped by marsh deposits. They rise from a few inches to 10 feet above the marsh. Radiocarbon dating indicates that the wide beach ridge in the northeast corner of photograph 3 A was part of the shoreline 2,100–2,200 years ago and that the cheniers become progressively younger seaward. The prominent one just back of the modern beach and adjacent mudflat is dated at 600–800 years before present.

La. 4. Mississippi delta: Levees and abandoned distributaries

County: Plaquemines Parish.
Lat 29°43′ N.; long 89°59′ W
Number of photographs: 1.
Photograph scale: 1:30,000.
Focal length: 6 in.
Date flown: Feb. 22, 1956.
Map reference: U.S. Geol. Survey Pointe a la Hache 15-min quadrangle, scale 1:62,500.
Geology reference: Welder, F. A., 1959, Processes of deltaic sedimentation in the lower Mississippi River: Louisiana State Univ., Coastal Studies Inst., Tech. Rept. 12, 90 p.; see fig. 5.

Features illustrated (set no. La. 4 in southeast corner of photograph).—Levee west of river attains a width of about 1 mile and stands about 5 feet above the river. Except where cleared by man, the levee is wooded. East of the river are several abandoned distributaries, such as River Aux Chenes in the northeast quadrant of the photograph.

La. 5. Mississippi delta: Dry Cypress Bayou, an inactive distributary

County: Plaquemines Parish.
Lat 29°15′ N.; long 89°31′ W.
Number of photographs: 1.
Photograph scale: 1:30,000.

Focal length: 6 in.
Date flown: Mar. 25, 1956.
Map reference: U.S. Geol. Survey Empire and Venice 15-min quadrangles, scale 1:62,500.
Geology reference: Welder, F. A., 1959, Processes of deltaic sedimentation in the lower Mississippi River: Louisiana State Univ., Coastal Studies Inst., Tech. Rept. 12, 90 p.; see fig. 7.

Features illustrated (set no. La. 5 in southeast corner of photograph).—This bayou, the last (southernmost) major abandoned distributary branching from the right bank of the Mississippi, flowed almost due south to the coast. Its mouth has been entirely closed, although a tidal channel connects it to Bay Coquette (southeast quadrant). This photograph shows only the last 4 miles of the bayou.

La. 6. Mississippi delta: Mangrove swamp and tidal estuaries near Grand Bay

County: Plaquemines Parish.
Lat 29°23′ N.; long 89°23′ W.
Number of photographs: 1.
Photograph scale: 1:30,000.
Focal length: 6 in.
Date flown: Mar. 25, 1956.
Map reference: U.S. Geol. Survey Venice 15-min quadrangle, scale 1:62,500.
Geology reference: Welder, F. A., 1959, Processes of deltaic sedimentation in the lower Mississippi River: Louisiana State Univ., Coastal Studies Inst., Tech. Rept. 12, 90 p.; see fig. 9.

Features illustrated (set no. La. 6 in southeast corner of photograph).—Mangrove swamp (dark areas) along the shore, tidal marsh cut by meandering estuaries, and straight artificial channels. The area is subsiding. Incipient beaches on part of coast. Grand Bay is in southeast quadrant.

La. 7. Mississippi delta: Cubits Gap

County: Plaquemines Parish.
Lat 29°12′ N.; long 89°14′ W.
Number of photographs: 1.
Photograph scale: 1:30,000.
Focal length: 6 in.
Date flown: Mar. 25, 1956.
Map reference: U.S. Geol. Survey West Delta and East Delta 15-min quadrangles, scale 1:62,500.
Geology reference: Welder, F. A., 1959, Processes of deltaic sedimentation in the lower Mississippi River: Louisiana State Univ., Coastal Studies Inst., Tech. Rept. 12, p. 25–38.

Features illustrated (set no. La. 7 in northwest corner of photograph).—Pilottown (southwest quadrant) stands on the natural levee on the left (east) bank of the Mississippi River. A crevasse that opened in this levee about a century ago, northwest of Pilottown and about 3 miles upstream from Head of Passes (south edge of photograph), is now Cubits Gap (northwest quadrant). Three distributaries diverge from Cubits Gap: Main Pass which runs north from the main channel, Octave Pass which trends northeast, and Raphael Pass which flows east. Mississippi sediment carried by these distributaries has converted more than 100 square miles of the Gulf of Mexico into land and fresh-water lakes. The mouths of several distributaries fed by Octave Pass are shown in La. 8.

La. 8. Mississippi delta: Mouth of Dead Women Pass

County: Plaquemines Parish.
Lat 29°14′ N.; long 89°08′ W.
Number of photographs: 1.
Photograph scale: 1:30,000.
Focal length: 6 in.
Date flown: Feb. 23, 1956.
Map reference: U.S. Geol. Survey East Delta and Breton Island 15-min quadrangles, scale 1:62,500.
Geology reference: Welder, F. A., 1959, Processes of deltaic sedimentation in the lower Mississippi River: Louisiana State Univ., Coastal Studies Inst., Tech. Rept. 12, 90 p.

Features illustrated (set no. La. 8 in southeast corner of photograph).—Area of active sedimentation near mouth of Dead Women Pass (northeast quadrant). Beaches are virtually absent. Area is a network of large and small distributaries bordered by marsh, which encloses many fresh-water ponds. These passes discharge part of the water that flows through Cubits Gap shown in La. 7. Most of the land shown in this photograph has been built since about 1900.

La. 9. Mississippi delta: Southwest Pass

County: Plaquemines Parish.
Lat 28°57′ N.; long 89°23′ W.
Number of photographs: 2.
Photograph scale: 1:30,000.
Focal length: 6 in.
Date flown: Mar. 25, 1956.
Map reference: U.S. Geol. Survey Southwest Pass 15-min quadrangle, scale 1:62,500.
Geology reference: Welder, F. A., 1959, Processes of deltaic sedimentation in the lower Mississippi River: Louisiana State Univ., Coastal Studies Inst., Tech. Report. 12, 90 p.

Features illustrated (set nos. La. 9 A–B in southeast corner of photographs).—These two photographs show the lower 7 miles of the pass but do not provide stereoscopic coverage. The land areas are largely marsh. Jetties extend from the mouth of the pass for nearly 2 miles beyond limit of the marsh.

Maine 1. Cirques on Mount Katahdin

County: Piscataquis.
Lat 45°55′ N.; long 68°55′ W.
Number of photographs: 3.
Photograph scale: 1:63,000.
Focal length: 6 in.
Date flown: June 30, 1952.
Map reference: U.S. Geol. Survey Katahdin, Harrington Lake, Telos Lake, and Traveler Mountain 15-min quadrangles, scale 1:62,500.

Geology reference: Caldwell, D. W., 1960, The geology of Baxter State Park and Mount Katahdin: Maine Geol. Survey State Park Geol. Ser. 2, 54 p.; map, scale 1:284,000.

Features illustrated (set nos. Maine 1 A–C in southeast corner of photographs).—Mount Katahdin rises 2,000–4,000 feet above the surrounding lowlands. The mountain, made of granite, has a broad gently sloping summit upland that is cut into by prominent glacial cirques (southeast quadrant of photograph 1 B). Some of the cirque headwalls form arêtes or knife-edge ridges. Small north-trending moraines dam four small ponds about 2 miles northeast of the highest peaks. Landslides scar the slopes of the mountains on west side of photograph 1 B (Mount Coe and South Brother). In the western part of the same photograph, the light-colored curving bands on the slopes in forested areas are blown-down trees attributed to the 1938 hurricane. It is not clear why the areas of blown-down trees occur in bands.

Maine 2. The Horseback along Sunkhaze Stream

County: Hancock.
Lat 44°57′ N.; long 68°25′ W.
Number of photographs: 3.
Photograph scale: 1:24,000.
Focal length: 6 in.
Date flown: May 1, 1956.
Map reference: U.S. Geol. Survey Great Pond 15-min quadrangle, scale 1:62,500.
Geology reference: Stone, G. H., 1899, The glacial gravels of Maine: U.S. Geol. Survey Mon. 34, p. 108 and pl. 42. Leavitt, H. W., and Perkins, E. H., 1935, Glacial geology of Maine: Maine Tech. Expt. Sta. Bull. 30, v. 2. Mon. 34, out of print.

Features illustrated (set nos. Maine 2 A–C in northeast corner of photographs).—This gravel ridge—an ice-channel filling or esker—crosses the area from northwest to southeast. It is virtually continuous, as much as 70 feet high, and is bordered by swamps and, locally, by kames. The adjacent rounded hills are of granitic rock.

Maine 3. Somes Sound and Sargent Mountain, Mount Desert Island

County: Hancock.
Lat 44°20′ N.; long 68°17′ W.
Number of photographs: 3.
Photograph scale: 1:24,000.
Focal length: 6 in.
Date flown: May 7, 1956.
Map reference: U.S. Geol. Survey Mount Desert and Bar Harbor 15-min quadrangles, scale 1:62,500.
Geology reference: Chapman, C. A., 1962, The geology of Mount Desert Island, Maine, with explanation and descriptive field guide: Ann Arbor, Mich., Edwards Bros., 52 p. Chapman, C. A., and Rioux, R. L., 1958, Statistical study of topography, sheeting, and jointing in granite, Acadia National Park, Maine: Am. Jour. Sci., v. 256, p. 111–127.

Features illustrated (set nos. Maine 3 A–C in northeast corner of photographs).—This island, largely of granitic rock, is cut by through-going U-shaped glacial valleys containing many small rock-basin lakes. These photographs include a segment of the more rugged part of the island. Sargent Mountain (northeast quadrant of photograph 3 B) rises more than 1,300 feet above Somes Sound, a small fiord (west edge of same exposure). Preglacial valleys trending just east of north were scoured and reshaped by glaciers moving across the island from the northwest, so the dominant trend of valley and ridge is now slightly west of north. Many ridges are asymmetric and have steeper slopes on their east side (Norumbega Mountain, southwest quadrant of photograph 3 B).

Md. 1. Falls of the Potomac

County: Montgomery and Fairfax.
Lat 39°00′ N.; long 77°15′ W.
Number of photographs: 4.
Photograph scale: 1:19,000.
Focal length: 6 in.
Date flown: Mar. 18, 1963.
Map reference: U.S. Geol. Survey Seneca, Rockville, Vienna, and Falls Church 7½-min quadrangles, scale 1:24,000.
Geology reference: Reed, J. C., Jr., and Jolly, Janice, 1963, Crystalline rocks of the Potomac River gorge near Washington, D.C.: U.S. Geol. Survey Prof. Paper 414-H, p. H1–H15; geol. map (pl. 2), scale 1:12,000.

Features illustrated (set nos. Md. 1 A–D in southeast corner of photographs).—The photographs show Great Falls (white water in northeast quadrant of photograph 1 B) and a narrow gorge downstream. Bear Island, a narrow rocky belt, lies east of the gorge between it and the Chesapeake and Ohio Canal. West of the river is an abandoned channel. The rock is a bedded sequence of mica schist and quartzite that has interlayered amphibolite exposed in a series of nearly isoclinal folds. The gorge of the Potomac River that marks the Fall Zone begins at Great Falls in the Piedmont province and extends southeastward for about 10 miles to the inner edge of the coastal plain near Washington. The flow of the river on the date the photographs were taken was about 43,500 cubic feet per second, 4 feet below flood stage.

Md. 2. Scientists Cliffs

County: Calvert.
Lat 38°31′ N.; long 76°31′ W.
Number of photographs: 3.
Photograph scale: 1:28,400.
Focal length: 6 in.
Date flown: Dec. 17, 1953.
Map reference: U.S. Geol. Survey Prince Frederick 7½-min quadrangle, scale 1:24,000.
Geology reference: Clark, W. B., Shattuck, G. B., and Dall, W. H., 1904, The Miocene deposits of Maryland, *in* Miocene [volume]: Maryland Geol. Survey, p. xxi–xciv. Singewald,

J. T., Jr., and Slaughter, T. H., 1949, Shore erosion in Tidewater Maryland: Maryland Dept. Geology, Mines, and Water Resources Bull. 6, p. 19–118.

Features illustrated (set nos. Md. 2 A–C in southeast corner of photographs).—These cliffs on the west shore of Chesapeake Bay cut off along an almost straight line the intricately dissected upland of southern Maryland carved in flat-lying beds of sandy clay, sand, and clay (Choptank and Calvert Formations of Miocene age). There is a narrow sand beach at the base of the cliffs. During the last 100 years, most of the cliffs have retreated; the total distance ranges from about 250 to 480 feet. From the beach, the floor of the bay declines very gently eastward and is marked by as many as eight submerged bars within not more than 1,000 feet offshore.

Mass. 1. Dunes and beaches at Provincetown

County: Barnstable.
Lat 42°04′ N.; long 70°12′ W.
Number of photographs: 3.
Photograph scale: 1:60,000.
Focal length: 6 in.
Date flown: May 6, 1960.
Map reference: U.S. Geol. Survey Provincetown 7½-min quadrangle, scale 1:24,000.
Geology reference: Davis, W. M., 1957, Geographical essays; chap. 25, The outline of Cape Cod: New York, Dover Publications, Inc., p. 690–724. Smith, H. T. U., and Messinger, Curtis, 1959, Geomorphic studies of the Provincetown dunes, Cape Cod, Massachusetts: U.S. Office of Naval Research, Geog. Branch, Tech. Rept. 1, 62 p.

Features illustrated (set nos. Mass. 1 A–C in northeast corner of photographs).—Sand dunes cover the tip of Cape Cod. Those dunes in the northern half of Cape Cod are active and largely bare; those to the south are stabilized by vegetation. A considerable part of the end of the Cape, perhaps all of it, was built by marine processes. Longshore transport from the east extended the point northward and northwestward, whereas the west end of the cape was eroded to build the east-curving spit on the south side that protects Provincetown Harbor. Submerged sandbars are visible offshore. Those on the north side parallel the shore; those to the south in Provincetown Harbor trend roughly at right angles to the shore.

Mass. 2. Meandering tidal creeks in salt marsh near Barnstable

County: Barnstable.
Lat 41°44′ N.; long 70°21′ W.
Number of photographs: 3.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: July 13, 1952.
Map reference: U.S. Geol. Survey Hyannis 7½-min quadrangle, scale 1:24,000.
Geology reference: Redfield, A. C., 1965, Ontogeny of a salt marsh estuary: Science, v. 174, p. 50–55.

Features illustrated (set nos. Mass. 2 A–C in southeast corner of photographs).—Carbon-14 dating of peat samples from various positions and depths have enabled Redfield to reconstruct the history of the marsh. He believes that as sea level has risen relative to the land during the last 4,000 years, the salt marsh has been built out into the bay protected by the eastward growth of the sandspit (Sandy Neck, north half of photograph 2 B). The presence of meandering channels in sand on the edge of the bay (southeast quadrant of photograph 2 B) suggests that the intricate meander patterns of the tidal streams in the marsh originated from such meanders. During the gradual filling of the bay, the marsh extends to the margins of these meandering channels. The creeks are now in quasi-equilibrium with the hydraulic forces that arise from the quantity of water that they must carry in response to the rhythm of the tide. Sand dunes with conspicuous blowouts mantle Sandy Neck.

Mich. 1. Shore features of Glacial Lake Duluth

County: Ontonagon.
Lat 46°42′ N.; long 89°30′ W.
Number of photographs: 5.
Photograph scale: 1:27,500.
Focal length: 6 in.
Date flown: Apr. 28, 1944.
Map reference: U.S. Geol. Survey Bergland NE. and Matchwood NW. 7½-min quadrangles, scale 1:24,000.
Geology reference: Leverett, Frank, 1928, Moraines and shorelines of the Lake Superior basin: U.S. Geol. Survey Prof. Paper 154–A, p. 1–73. Hack, J. T., 1965, Postglacial drainage evolution and stream geometry in the Ontonagon area, Michigan: U.S. Geol. Survey Prof. Paper 504–B, p. B1–B40.

Features illustrated (set nos. Mich. 1 A–E in northeast corner of photographs).—The plain in the north half of the photographs has a thin mantle of till overlying interbedded till and lake deposits and in photograph 1 B shows glacial fluting by ice that moved southward beyond the limits of the area shown in these photographs. Hills in the southern part of the area are volcanic rocks of Precambrian age. Beach and wave-cut cliff can be seen in the southern half of photograph 1 B, together with a sand and gravel bar across the middle part of bay (southwest quadrant of photograph 1 C). Tombolos are present in the northwest and southeast quadrants of photograph 1 E; the one in the southeast quadrant is outside the area of overlap. The faint curved trace of the younger and lower shoreline of Lake Duluth is seen in the north center of photograph 1 A.

Mich. 2. Postglacial drainage controlled by glacial flutings

County: Ontonagon.
Lat 46°48′ N.; long 89°25′ W.
Number of photographs: 2.
Photograph scale: 1:27,500.

Focal length: 6 in.
Date flown: Oct. 19, 1943.
Map reference: U.S. Geol. Survey Ontonagon 15-min quadrangle, scale 1:62,500.
Geology reference: Leverett, Frank, 1928, Moraines and shorelines of the Lake Superior basin: U.S. Geol. Survey Prof. Paper 154–A, p. 1–73. Hack, J. T., 1965, Postglacial drainage evolution and stream geometry in the Ontonagon area, Michigan: U.S. Geol. Survey Prof. Paper 504–B, p. B1–B40.

Features illustrated (set nos. Mich. 2 A–B in northeast corner of photographs).—A till plain veneered with very thin lake sediments and crossed by glacial grooves or flutings which have controlled the postglacial drainage pattern. Cranberry River in the east part of photograph 2 B is entrenched 40–80 feet in glacial till and bedrock. The wavelength of meanders of Cranberry River changes abruptly near the corner of the road. The riverbed is in till and alluvium north of this point and in shale and sandstone bedrock south of it. Beaver ponds in glacial grooves in south part of photograph 2 A.

Mich. 3. Bedrock and coastal features on Keweenaw Peninsula

County: Keweenaw.
Lat 47°26′ N.; long 88°12′ W.
Number of photographs: 2.
Photograph scale: 1:27,200.
Focal length: 6 in.
Date flown: Oct. 8, 1943.
Map reference: U.S. Geol. Survey Eagle Harbor 7½-min quadrangle, scale 1:24,000.
Geology reference: Cornwall, H. R., and Wright, J. C., 1954, Bedrock geology of the Eagle Harbor quadrangle, Michigan: U.S. Geol. Survey Geol. Quad. Map GQ–36.

Features illustrated (set nos. Mich. 3 A–B in northeast corner of photographs).—Northward-dipping basalt and andesite flows and conglomerates of Keweenawan age form cuestas parallel to the south shore of Lake Superior. Conspicuous lineaments trending a little west and a little east of north, some of which are stream valleys, are caused by faults of small displacement. Throughout most of the area, the bedrock is concealed beneath glacial drift. Prominent dunes are behind the present curving beach. The shoreline east of the dunes is controlled by an outcrop of lava flow behind which are numerous abandoned beach ridges. The gray area at the foot of the bedrock slope a mile east of the dunes is mine tailings.

Mich. 4. Cuestas and strandlines on Keweenaw Peninsula

County: Keweenaw.
Lat 47°27′ N.; long 88°03′ W.
Number of photographs: 4.
Photograph scale: 1:27,200.
Focal length: 6 in.
Date flown: Oct. 8, 1943.
Map reference: U.S. Geol. Survey Delaware 7½-min quadrangle, scale 1:24,000.
Geology reference: Cornwall, H. R., 1954, Bedrock geology of the Delaware quadrangle, Michigan: U.S. Geol. Survey Geol. Quad. Map GQ–51.

Features illustrated (set nos. Mich. 4 A–D in northeast corner of photographs).—Northward-dipping conglomerates and lava flows of Precambrian age form cuestas parallel to the south shore of Lake Superior and submerged reefs offshore. Lineaments striking N. 10°–15° W. across the conglomerate ridge in the center of photographs 4 C mark the trend of minor faults of a type that locally contains native copper veins in the lava series to the south. An esker in the center of photograph 4 A trends northward through a fault-controlled gap in the lava ridge to merge with a delta(?) graded to the highest level of Lake Algonquin. The supposed delta is dissected by a stream that flows north through a gap in a conglomerate ridge and that has built a fan or possibly a delta graded to a lower glacial lake level.

Mich. 5. Esker near Black Lake

County: Cheboygan.
Lat 45°23′ N.; long 84°25′ W.
Number of photographs: 2.
Photograph scale: 1:17,000.
Focal length: 6 in.
Date flown: May 5, 1953.
Map reference: U.S. Geol. Survey Tower 15-min quadrangle, scale 1:62,500.

Features illustrated (set nos. Mich. 5 A–B in northeast corner of photographs).—A narrow steep-sided esker about 30–60 feet high crosses these photographs from northwest to southeast. The ridge is bordered by swamp and in places by much larger masses of drift, probably kames.

Mich. 6. Beach ridges at Hammond Bay

County: Presque Isle.
Lat 45°31′ N.; long 84°07′ W.
Number of photographs: 2.
Photograph scale: 1:17,000.
Focal length: 6 in.
Date flown: Apr. 25, 1954.
Map reference: U.S. Geol. Survey Grace and Onaway 15-min quadrangles, scale 1:62,500.

Features illustrated (set nos. Mich. 6 A–B in northeast corner of photographs).—These regular curving parallel beach ridges, about 40 in number, form a mile-wide belt parallel to the shore at the west end of Lake Huron. The beaches and intervening swales form a platform that rises from the lakeshore to a height of about 40 feet at the inner edge of the beach-ridge belt.

Minn. 1. Attenuated drumlins east of Hewitt

County: Todd.
Lat 46°20′ N.; long 95°03′ W.

Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: July 21, 1963.
Map reference: U.S. Geol. Survey Brainerd sheet, scale 1:250,000.
Geology reference: Wright, H. E., 1957, Stone orientation in Wadena drumlin field, Minnesota: Geog. Annaler, v. 39, no. 1, p. 19–31; see fig. 3.

Features illustrated (set nos. Minn. 1 A–B in northeast corner of photographs).—These long ridges, largely cultivated land, range from 15 to 30 feet in height and are symmetrical in cross section and in profile. Side slopes are less than 3°. The ice that molded the drumlins moved south-southwest. The ridges consist largely of a yellowish-brown sandy calcareous till. Streams occupy shallow valleys between and parallel to the drumlins. (Compare with Mont. 5.)

Minn. 2. Ice-channel filling east of Grand Rapids

County: Itasca.
Lat 47°17′ N.; long 93°18′ W.
Number of photographs: 2.
Photograph scale: 1:17,000.
Focal length: 6 in.
Date flown: May 2, 1947.
Map reference: U.S. Geol. Survey Calumet 7½-min quadrangle, scale 1:24,000.
Geology reference: Cotter, R. D., Young, H. L., and Winter, T. C., 1964, Preliminary surficial geologic map of the Mesabi-Vermilion Iron Range area, northeastern Minnesota: U.S. Geol. Survey Misc. Geol. Inv. Map I–403, scale 1:125,000.

Features illustrated (set nos. Minn. 2 A–B in northeast corner of photographs).—A prominent northwest-trending ridge indented and bordered by kettle lakes extends diagonally across the photographs. In the northwest quadrant of photograph 2 B the ridge is narrow and steep sided, but to the southeast it becomes a flat-topped ridge as much as a quarter of a mile wide. The ridge is probably an ice-channel filling. It is bordered by a rolling till-covered plain dotted by lakes and swamps. Swan River follows a winding course across the plain.

Miss. 1. Ancient meanders near Grace archaeologic site

County: Issaquena.
Lat 32°59′ N.; long 90°58′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Nov. 30, 1949.
Map reference: U.S. Geol. Survey Lorenzen 15-min quadrangle, scale 1:62,500.
Geology reference: Fisk, H. N., 1944, Geological investigations of the alluvial valley of the lower Mississippi River: Vicksburg, Miss., Mississippi River Comm., 78 p.; see pl. 15, sheet 3, and pl. 22, sheet 9.

Features illustrated (set nos. Miss. 1 A–B in southeast corner of photographs).—The broad forest and swamp-covered meander (Lafayette Lake; part of Fisk's stage 10) bisects an older meander, largely cultivated land (stage 9) in the northeast quadrant of photograph 1 B. The area south and east of these two meanders (southeast quadrant of photograph 1 A) lacks a scroll pattern and is a remnant of a depositional segment of the Mississippi River flood plain that is considerably older (stage B3) than the two ages of meanders. The Indian mounds southeast of the junction of the two meanders (just northeast of center of photograph 1 A and west of road) are the Grace archaeologic site.

Miss. 2. Meander scrolls on flood plain near Tippo

County: Tallahatchie.
Lat 33°53′ N.; long 90°13′ W.
Number of photographs: 3.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Sept. 21, 1962.
Map reference: U.S. Geol. Survey Philipp 15-min quadrangle, scale 1:62,500.

Features illustrated (set nos. Miss. 2 A–C in southeast corner of photographs).—Meander scrolls, oxbow lakes, and sloughs on alluvial plain of Yazoo Basin about 50 miles northeast of Greenville. One set of meander scrolls covers most of photograph 2 A, except where intersected by younger scrolls in the southwest corner of the photograph. Much of the area is cleared; only the larger depressions of the meander scrolls are tree covered. The local relief ranges from less than 5 to nearly 10 feet.

Mo. 1. Precambrian core of Saint Francois Mountains

County: Iron.
Lat 37°37′ N.; long 90°38′ W.
Number of photographs: 3.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Oct. 18, 1954.
Map reference: U.S. Geol. Survey Ironton 15-min quadrangle, scale 1:62,500.
Geology reference: McCracken, M. H., compiler, 1961, Geologic map of Missouri: Missouri Geol. Survey and Water Resources Div., scale 1:500,000.

Features illustrated (set nos. Mo. 1 A–C in southeast corner of photographs).—Rounded hills of Precambrian crystalline rocks stand above the lowlands underlain by sedimentary rocks of Cambrian age in the center of the Saint Francois Mountains.

Mo. 2. Salem Plateau along Crooked Creek

County: Dent.
Lat 37°50′ N.; long 91°24′ W.
Number of photographs: 4.
Photograph scale: 1:24,000.
Focal length: 6 in.
Date flown: July 8, 1959.

Map reference: U.S. Geol. Survey Steelville 15-min quadrangle, scale 1:62,500.
Geology reference: Snyder, F. G., and Gerdemann, P. E., 1965, Explosive igneous activity along an Illinois-Missouri-Kansas axis: Am. Jour. Sci., v. 263, no. 6, p. 465–493.

Features illustrated (set nos. Mo. 2 A–D in southwest corner of photographs).—These photographs show a part of the Salem Plateau section of the Ozark Plateaus on the northwest side of the Saint Francois Mountains. Essentially flatlying dolomite beds, largely of Ordovican age, form wooded hills that rise 100–200 feet above narrow cultivated valleys. Crooked Creek, a tributary of the Meramec River, flows northward across the northeast quadrant of photograph 2 C. The cultivated uplands west of the river include the central part of the Crooked Creek disturbance, a complex ring structure 3–4 miles in diameter bounded by high-angle faults. None of the detailed structural features of this disturbance can be seen in the photographs.

Mo. 3. Subterranean stream piracy near Jefferson City

County: Cole.
Lat 38°33′ N.; long 92°04′ W.
Number of photographs: 4.
Photograph scale: 1:24,000.
Focal length: 6 in.
Date flown: Apr. 7, 1965.
Map reference: U.S. Geol. Survey Jefferson City 15-min quadrangle, scale 1:62,500.
Geology reference: Bretz, J H., 1965, Geomorphic history of the Ozarks of Missouri: Missouri Geol. Survey and Water Resources Div., 2d ser., v. 41, p. 111.

Features illustrated (set nos. Mo. 3 A–D in northeast corner of photographs).—Bluffs on the south side of the narrow flood plain of the Missouri River expose flatlying beds of cherty dolomite that to the south form steep-sided hills 150–300 feet high. The meandering Moreau River (west edge of photograph 3 B) enters the Missouri by way of a gorge through a narrow peninsula of rock. A recently abandoned course of the Moreau River extends eastward just south of the Missouri trench to join the Osage River less than a mile from where the latter joins the Missouri. The modern Moreau River gorge may be an example of subterranean stream piracy.

Mont. 1. Lewis overthrust near Chief Mountain, Glacier National Park

County: Glacier.
Lat 48°56′ N.; long 113°37′ W.
Number of photographs: 3.
Photograph scale: 1:60,000.
Focal length: 6 in.
Date flown: Aug. 25, 1958.
Map reference: U.S. Geol. Survey Chief Mountain 30-min quadrangle, scale 1:125,000.
Geology reference: Dyson, J. L., 1960, The geologic story of Glacier National Park: Glacier Nat. History Assoc. Spec. Bull. 3 [rev.], 24 p.

Features illustrated (set nos. Mont. 1 A–C in southeast corner of photographs).—Chief Mountain, a steep-sided block of resistant argillite of the Belt Series of Precambrian age (just south of center of photograph 1 C), rests on a broad ridge of Cretaceous shale. Chief Mountain is an outlier of the Lewis overthrust, as are the small hills southwest of the mountain. Elsewhere the virtually flat-lying rocks of the Belt Series above the thrust plane form curving and branching mountain ridges (light-colored areas in most of photograph 1 B) with steep slopes or cliffs that are commonly the headwalls of cirques and are partly mantled by talus deposits. The Precambrian rocks were thrust eastward over the Cretaceous strata. The trace of the overthrust zigzags back and forth, more or less following the base of the light-colored cliffs in photograph 1 A.

Mont. 2. Blackfoot Glacier, Glacier National Park

County: Glacier.
Lat 48°36′ N.; long 113°40′ W.
Number of photographs: 4.
Photograph scale: 1:60,000.
Focal length: 6 in.
Date flown: Aug. 25, 1958.
Map reference: U.S. Geol. Survey Chief Mountain 30-min quadrangle, scale 1:125,000.
Geology reference: Dyson, J. L., 1952, Glaciers and glaciation in Glacier National Park: Glacier Nat. History Assoc. Spec. Bull. 2 [rev.], 24 p.

Features illustrated (set nos. Mont. 2 A–D in southeast edge of photographs).—This glacier hangs on the headwall of a north-facing cirque (southwest quadrant of photograph 2 B) carved in more or less flat-lying rocks of the Belt Series. The cirques contain bare moraines of Recent age. Arêtes and horns are conspicuous. The major valleys are U-shaped and contain conspicuous steps or glacial stairways.

Mont. 3. Moraines and gravel benches near Deep Creek

County: Teton.
Lat 47°43′ N.; long 112°32′ W.
Number of photographs: 3.
Photograph scale: 1:37,200.
Focal length: 6 in.
Date flown: July 13, 1955.
Map reference: U.S. Geol. Survey Lake Theboe and Split Rock Lake 7½-min quadrangles, scale 1:24,000.
Geology reference: Alden, W. C., 1932, Physiography and glacial geology of eastern Montana and adjacent areas: U.S. Geol. Survey Prof. Paper 174, p. 46, 120, and pl. 1. Stebinger, Eugene, 1919, Oil and gas geology of the Birch Creek-Sun River area, northwestern Montana: U.S. Geol. Survey Bull. 691, p. 149–184.

Features illustrated (set nos. Mont. 3 A–C in southeast corner of photographs).—Deep Creek (north edge of photograph 3 A) is incised about 200 feet below an eastward sloping gravel bench that to the west partly buries low hills composed of closely folded Cretaceous sandstone and shale (northwest quadrant of photograph 3 B). The creek may have originated as an ice-marginal stream because it follows the north edge of Alden's Sun River glacier which flowed eastward onto the plains. South of Deep Creek are several east-trending lateral moraines and many small ponds and swamps.

Mont. 4. Dikes and domes in Bearpaw Mountains

County: Blaine.
Lat 48°12′ N.; long 109°10′ W.
Number of photographs: 3.
Photograph scale: 1:63,360.
Focal length: 6 in.
Date flown: Oct. 25, 1952.
Map reference: U.S. Geol. Survey Rattlesnake 15-min quadrangle, scale 1:62,500.
Geology reference: Hearn, B. C., Jr., Pecora, W. T., and Swadley, W. C., 1965, Geology of the Rattlesnake quadrangle, Blaine County, Montana: U.S. Geol. Survey Bull. 1181–B; geol. map (pl. 1), scale 1:31,680.

Features illustrated (set nos. Mont. 4 A–C in northeast section of photographs).—Domes, dikes, and other Eocene intrusive rocks arranged in radial pattern. Several domes, 1–2 miles in diameter, on the outer edge of the hills in the southwest quadrant of photograph 4 B are outlined by outward-dipping Cretaceous sedimentary rocks. The slightly elongate dome about 2 miles southeast of the center of the west edge of the photograph, has a core of igneous rock. An east-west dike is visible about half a mile to the north. The drainage is radial. To the west and to the southeast the bedrock is mantled by gravel deposits at several different levels.

Mont. 5. Ice-fluted till plain east of Havre

County: Phillips.
Lat 48°23′ N.; long 108°23′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: July 12, 1953.
Map reference: U.S. Geol. Survey Havre sheet, scale 1:250,000.
Geology reference: Colton, R. B., Lemke, R. W., and Lindvall, R. M., 1961, Glacial map of Montana east of Rocky Mountains: U.S. Geol. Survey Misc. Geol. Inv. Map I–327, scale 1:500,000.

Features illustrated (set nos. Mont. 5 A–B in northeast corner of photographs).—Till plain fluted by ice advancing from the northwest; the ridges are mainly elongated drumlins. Postglacial drainage forms a trellis pattern controlled by the flutes.

Mont. 6. Drift border near Martin Lake

County: Phillips.
Lat 48°49′ N.; long 107°55′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: July 20, 1954.
Map reference: U.S. Geol. Survey Glasgow sheet, scale 1:250,000.
Geology reference: Colton, R. B., Lemke, R. W., and Lindvall, R. M., 1961, Glacial map of Montana east of the Rocky Mountains: U.S. Geol. Survey Misc. Geol. Inv. Map I–327, scale 1:500,000.

Features illustrated (set nos. Mont. 6 A–B in northeast corner of photographs).—The linear ridge across the northern third of these photographs is part of a terminal moraine built by south-moving ice. The moraine separates an area of knob and kettle topography to the north from a well-drained and moderately dissected plain (outwash plain?) to the south. The conspicuous north-south valley that cuts across the entire area and the broad valley near the south edge of the photographs, which contains Martin Lake, are melt-water channels; the latter valley predates the moraine.

Mont. 7. Volcanic rocks and Cretaceous sediments in Bearpaw Mountains

County: Blaine.
Lat 48°02′ N.; long 109°16′ W.
Number of photographs: 2.
Photograph scale: 1:63,360.
Focal length: 6 in.
Date flown: Oct. 20, 1952.
Map reference: U.S. Geol. Survey Maddux and Rattlesnake 15-min quadrangles, scale 1:62,500.
Geology reference: Bryant, Bruce, Schmidt, R. G., Pecora, W. T., 1960, Geology of the Maddux quadrangle, Bearpaw Mountains, Blaine County, Montana: U.S. Geol. Survey Bull. 1081–C, p. 91–116; geol. map (pl. 3), scale 1:31,680.

Features illustrated (set nos. Mont. 7 A–B in northeast corner of photographs).—Tilted middle Eocene flows and pyroclastic rocks (west part of photograph 7 A) are separated by a southeast-trending fault from pre-volcanic Cretaceous and lower Tertiary sedimentary rocks. The beds of volcanic rock are cut off by the fault.

The volcanic rocks form small rugged hills with lower drainage density than the less rugged area to the east carved in the Cretaceous Bearpaw Shale. The area east of the fault includes extensive gravel benches at various levels.

Mont. 8. Diatreme and fault structures south of Bearpaw Mountains

County: Blaine.
Lat 47°50′ N.; long 109°12′ W.
Number of photographs: 3.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Aug. 22, 1956.

Map reference: U.S. Geol. Survey Bird Rapids 7½-min quadrangle, scale 1:24,000.

Geology reference: Reeves, Frank, 1924, Geology and possible oil and gas resources of the faulted area south of the Bearpaw Mountains, Montana: U.S. Geol. Survey Bull. 751–C, p. 71–114; geol. map (pl. 13), scale 1:125,000. 1946, Origin and mechanics of thrust faults adjacent to the Bearpaw Mountains, Montana: Geol. Soc. America Bull., v. 57, p. 1033–1047.

Features illustrated (set nos. Mont. 8 A–C in northeast corner of photographs).—On these photographs the dark areas are largely Bearpaw Shale, and the light areas are the underlying Judith River Formation which includes sandstone, siltstone, and shale. The Bearpaw Shale lies flat, but the Judith River Formation is raised up along high-angle faults and gently tilted. These bands or lineaments were thought by Reeves to be due to shallow deformation within a gravity slide sheet, the base of the sheet lying about 1,500 feet below the present valley floors.

The circular diatreme about 1,000 feet in diameter (near center of photograph 8 A) is a volcanic pipe filled with pyroclastic rocks; the light-colored patches near its border are blocks of younger Cretaceous and Tertiary formations, now eroded away, which have been dropped several thousand feet into the pipe (B. C. Hearn, Jr., written commun., 1964).

Mont. 9. Ice-marginal drainage channels east of Little Rocky Mountains

County: Phillips.
Lat 47°49′ N.; long 108°23′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: July 10, 1953.
Map reference: U.S. Geol. Survey Lewistown sheet, scale 1:250,000.
Geology reference: Colton, R. B., Lemke, R. W., and Lindvall, R. M., 1961, Glacial map of Montana east of the Rocky Mountains: U.S. Geol. Survey Misc. Geol. Inv. Map I–327, scale 1:500,000.

Features illustrated (set nos. Mont. 9 A–B in northeast corner of photographs).—A group of subparallel channels run southward across the uplands as shown in the center of photograph 9 B. These melt-water channels were cut when southeast-draining valleys from the Little Rocky Mountains were dammed by a tongue of early Wisconsin ice that came from the northeast.

Mont. 10. Desiccation cracks near Beaver Creek

County: Phillips.
Lat 47°51′ N.; long 108°14′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: July 10, 1953.
Map reference: U.S. Geol. Survey Lewistown sheet, scale 1:250,000.
Geology reference: Colton, R. B., Lemke, R. W., and Lindvall, R. M., 1961, Glacial map of Montana east of the Rocky Mountains: U.S. Geol. Survey Misc. Geol. Inv. Map I–327, scale 1:500,000.

Features illustrated (set nos. Mont. 10 A–B in northeast corner of photographs).—Giant desiccation cracks on the flat valley floor south of Beaver Creek. Some of the individual polygons are as much as 200 feet across. The valley floor is surrounded by hills of Cretaceous Bearpaw Shale.

Mont. 11. Antelope Sag

County: Sheridan.
Lat 48°41′ N.; long 104°27′ W.
Number of photographs: 3.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: July 9, 1949.
Map reference: U.S. Geol. Survey Antelope and Shippe Canyon 7½-min quadrangles, scale 1:24,000.
Geology reference: Witkind, I. J., 1959, Quaternary geology of the Smoke Creek-Medicine Lake, Grenora area, Montana and North Dakota: U.S. Geol. Survey Bull. 1073, p. 27–34, fig. 11.

Features illustrated (set nos. Mont. 11 A–C in northeast corner of photographs).—Antelope Sag is a faint depression across the upland now followed by the highway and the railroad that run north-south through the center of photograph 11 B. The sag marks the approximate location of an ancestral outwash channel now wholly concealed beneath till. Following the cutting of this old channel, the area was overridden by a westward-advancing ice sheet. During the subsequent eastward retreat of the ice front, melt water cut a new horseshoe-shaped channel around the ice margin. When the ice withdrew from the area, the north-trending ancestral valley was filled with till, and Big Muddy Creek drainage used the new channel west of Antelope.

Mont. 12. Dagmar Channel, an outwash channel separating two till sheets

County: Sheridan.
Lat 48°40′ N.; long 104°10′ W.
Number of photographs: 3.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: July 30, 1940.
Map reference: U.S. Geol. Survey Wolf Point sheet, scale 1:250,000.
Geology reference: Witkind, I. J., 1959, Quaternary geology of the Smoke Creek-Medicine Lake-Grenora area, Montana and North Dakota: U.S. Geol. Survey Bull. 1073, 80 p.; see geol. map (pl. 1), eastern part, scale 1:62,500.

Features illustrated (set nos. Mont. 12 A–C in northeast corner of photographs).—Dagmar Channel, about 1 mile wide, trends south across the central part of photograph 12 B. The area to the west is a till plain of an early Wisconsin(?) ice sheet, and it has a well-integrated drainage system. Dagmar Channel was cut by melt water flowing along the west edge of a younger ice sheet (Mankato age), and it is floored by well-sorted outwash sand and gravel; Clear Lake is a kettle at its eastern edge. East of Dagmar Channel the Mankato till plain retains its original knob-and-kettle topography; no integrated drainage system exists.

Mont. 13. Tilting of ancient courses of Madison River

County: Madison.
Lat 44°48′ N.; long 111°29′ W.
Number of photographs: 3.
Photograph scale: 1:59,000.
Focal length: 6 in.
Date flown: Sept. 6, 1954.
Map reference: U.S. Geol. Survey Cliff Lake and Hebgen Dam 15-min quadrangles, scale 1:62,500.
Geology reference: Myers, W. B., and Hamilton, Warren, 1964, Deformation accompanying the Hebgen Lake earthquake of August 17, 1959: U.S. Geol. Survey Prof. Paper 435-I, p. 55–98; see pl. 2 and figs. 47 and 48.

Features illustrated (set nos. Mont. 13 A–C in northeast corner of photographs).—The Madison River leaves its canyon (northeast corner of photograph 13 B) to flow along the north edge of broad Madison Valley. South of the river (largely in northwest quadrant of same photograph) are a flight of river terraces cut on Oligocene(?) rhyolite. The higher terraces, although considerably dissected, rise westward because of a general northeasterly tilting of much of the area shown in this photograph. The successively younger terraces are also tilted, but this tilting is not easy to see. A recent fault scarp bounds the west front of the Madison Range (east edge of photograph 13 B). There was a slight northeast tilt of this part of the Madison Valley during the Hebgen Lake earthquake. The cutting of the trough of Cliff Lake (near center of west edge of photograph 13 B) must postdate the formation of the high terraces east of the lake.

Mont. 14. Hebgen Lake earthquake: Preslide view of Madison River canyon

County: Madison.
Lat 44°49′ N.; long 111°26′ W.
Number of photographs: 3.
Photograph scale: 1:16,000.
Focal length: 8.25 in.
Date flown: Sept. 19, 1956.
Map reference: U.S. Geol. Survey Hebgen Dam 15-min quadrangle, scale 1:62,500.
Geology reference: Hadley, J. B., 1964, Landslides and related phenomena accompanying the Hebgen Lake earthquake of August 17, 1959: U.S. Geol. Survey Prof. Paper 435-K, p. 107–121.

Features illustrated (set nos. Mont. 14 A–C in northeast corner of photographs).—Madison River canyon prior to the Madison slide that descended the south wall of the canyon in the southwest quadrant of photograph 14 B. Dolomite buttress can be seen on the thickly wooded south wall of the canyon. The slide extended upriver (to northeast) to a point about at the center of photograph 14 B and downriver to the western edge of fan at mouth of south-draining dry wash; about a 1-mile segment of the canyon floor was buried. Rock Creek camp ground (later largely buried by slide) lies on the northwest side of the river.

Mont. 15. Hebgen Lake earthquake: The Madison slide

County: Madison.
Lat 44°49′ N.; long 111°26′ W.
Number of photographs: 4.
Photograph scale: 1:10,000.
Focal length: 8.25 in.
Date flown: Aug. 22, 1959.
Map reference: U.S. Geol. Survey Hebgen Dam 15-min quadrangle, scale 1:62,500.
Geology reference: Hadley, J. B., 1964, Landslides and related phenomena accompanying the Hebgen Lake earthquake of August 17, 1959: U.S. Geol. Survey Prof. Paper 435-K, p. 107–121.

Features illustrated (set nos. Mont. 15 A–D in north corner of photographs).—Thirty-seven million cubic yards of broken rock slid into the Madison River canyon and buried a mile of the river and highway to a depth of 100–200 feet and then rode some 400 feet up the opposite canyon wall. These photographs were taken 5 days after the earthquake. The south wall of Madison Canyon is formed by Precambrian schist and gneiss which are deeply weathered and fractured and which dip northward at high angles. These rocks were overlain and held in place by a dolomite buttress, a remnant of which still shows on the northwest side of the slide. Apparently the buttress failed, and the schists and gneisses broke along a curving, concave-upward plane and slid valleyward. Dolomite shows as a sinuous white ridge along the north edge of the slide. Much of the deeper part of the slide, concealed by loose surface material, consists of blocks of bedrock which slid as distinct units. Earthquake Lake, along the east edge of the slide, is filled with debris and as yet is not high enough to submerge all trees.

Mont. 16. Hebgen Lake earthquake: Hebgen fault scarp along northwest arm of Hebgen Lake

County: Gallatin.
Lat 44°52′ N.; long 111°20′ W.
Number of photographs: 3.
Photograph scale: 1:10,000.
Focal length: 8.25 in.
Date flown: Aug. 22, 1959.
Map reference: U.S. Geol. Survey Hebgen Dam 15-min quadrangle, scale 1:62,500.
Geology reference: U.S. Geological Survey, 1964, Geology of the Hebgen Lake, Montana, earthquake of August 17, 1959: U.S. Geol. Survey Prof. Paper 435, 242 p.

Features illustrated (set nos. Mont. 16 A–C in east corner of photographs).—Hebgen Dam and the northwest part of lake 5 days after the earthquake. Photographs show the submerged north shore and landslides into the lake. Hilgard Lodge, completely destroyed, is near the southeast edge of photograph 16 B. The Hebgen fault scarp, partly concealed by trees northeast of the lake, follows the southwest flank of Hebgen Ridge where the height of the scarp ranges from 1 to 22 feet. Colluvium is the dominant material offset. Locally, small subsidiary scarps parallel or diverge from the main scarp. Northeast of the dam the main scarp curves eastward around a colluvial fan which has slid toward the dam. Earthfill along the downstream side of Hebgen Dam shows erosion channels formed when the dam was crested by the waves of the seiche set up in Hebgen Lake at the time of the earthquake.

Mont. 17. Hebgen Lake earthquake: Highway damage along north shore of Hebgen Lake

County: Gallatin.
Lat 44°51′ N.; long 111°18′ W.
Number of photographs: 2.
Photograph scale: 1:10,000.
Focal length: 8.25 in.
Date flown: Aug. 22, 1959.
Map reference: U.S. Geol. Survey Hebgen Dam 15-min quadrangle, scale 1:62,500.
Geology reference: Witkind, I. J., 1964, Structural damage in the Hebgen Lake-West Yellowstone area: U.S. Geol. Survey Prof. Paper 435–B, p. 5–11.

Features illustrated (set nos. Mont. 17 A–B in east corner of photographs).—Submerged shoreline and highway along the northeast side of Hebgen Lake near Kirkwood Motel. Across the highway from the motel, a curving line of driftwood parallel to the shore marks the limit of one advance of the seiche. Two sand spouts in alluvial fill appear as small white spots just south of the access road which extends to the lake from the highway.

Mont. 18. Hebgen Lake earthquake: Submerged north shore of Hebgen Lake

County: Gallatin.
Lat 44°49′ N.; long 111°16′ W.
Number of photographs: 2.
Photograph scale: 1:10,000.
Focal length: 8.25 in.
Date flown: Aug. 22, 1959.
Map reference: U.S. Geol. Survey Hebgen Dam 15-min quadrangle, scale 1:62,500.
Geology reference: Myers, W. B., and Hamilton, Warren, 1964 Deformation accompanying the Hebgen Lake earthquake of August 17, 1959: U.S. Geol. Survey Prof. Paper 435–I, p. 75–77.

Features illustrated (set nos. Mont. 18 A–B in east corner of photographs).—Alluvial fan at the mouth of Dave Johnson Creek (southern quadrant of photograph 18 B) submerged by northward tilting of the lake. Rows of inundated willows mark former shoreline. Small white spots near the southeast corner of the fan are sand spouts. Hebgen fault scarp is visible just behind cabins at head of the fan.

Mont. 19. Hebgen Lake earthquake: Red Canyon fault scarp along south flank of Kirkwood Ridge

County: Gallatin.
Lat 44°52′ N.; long 111°13′ W.
Number of photographs: 2.
Photograph scale: 1:10,000.
Focal length: 8.25 in.
Date flown: Aug. 22, 1959.
Map reference: U.S. Geol. Survey Tepee Creek 15-min quadrangle, scale 1:62,500.
Geology reference: Witkind, I. J., 1964, Reactivated faults north of Hebgen Lake: U.S. Geol. Survey Prof. Paper 435–G, p. 37–50.

Features illustrated (set nos. Mont. 19 A–B in east corner of photographs).—In these photographs the new scarps along the Red Canyon fault can be traced for 2 miles on the south flank of Kirkwood Ridge. The ridge is composed of steeply dipping Paleozoic strata; the vertical limestone ribs are part of the Mission Canyon Limestone of the Madison Group (Mississippian), and the dark-gray band immediately northeast is the Amsden Formation. The scarp, 6–15 feet high, displaces colluvium and generally parallels bedding in the exposed rocks higher on the slope.

Mont. 20. Hebgen Lake earthquake: Emerged south shore of Hebgen Lake

County: Gallatin.
Lat 44°45′ N.; long 111°14′ W.
Number of photographs: 2.
Photograph scale: 1:10,000.
Focal length: 8.25 in.
Date flown: Aug. 22, 1959.
Map reference: U.S. Geol. Survey West Yellowstone, Hebgen Dam, and Tepee Creek 15-min quadrangles, scale 1:62,500.
Geology reference: Myers, W. B., and Hamilton, Warren, 1964, Deformation accompanying the Hebgen Lake earthquake of August 17, 1959: U.S. Geol. Survey Prof. Paper 435–I, p. 70–77.

Features illustrated (set nos. Mont. 20 A–B in east corner of photographs).—The south shore of Hebgen Lake has raised beaches, broad mudflats, and piers on dry land that was exposed when the lake was displaced northeastward. The land area on the northeast side of photograph 20 B is Edwards Island, once surrounded by water but now by mudflats that extend to the north shore of the lake, outside the area shown in these photographs.

Mont. 21. Hebgen Lake earthquake: Sediment in streams

County: Gallatin.
Lat 44°47′ N.; long 111°10′ W.
Number of photographs: 2.
Photograph scale: 1:10,000.
Focal length: 8.25 in.
Date flown: Aug. 22, 1959.
Map reference: U.S. Geol. Survey Tepee Creek 15-min quadrangle, scale 1:62,500.
Geology reference: U.S. Geological Survey, 1964, Geology of the Hebgen Lake, Montana, earthquake of August 17, 1959: U.S. Geol. Survey Prof. Paper 435, 242 p.

Features illustrated (set nos. Mont. 21 A–B in east corner of photographs).—Grayling Creek (north quadrant) discharges turbid water into Grayling Arm of Hebgen Lake. The white color is a result of reflection of fine-grained sediment. Spring-fed streams in volcanic rocks carried large amounts of very fine volcanic sediment in suspension, and the streams remained murky for several months. By contrast, streams heading in sedimentary rocks were murky for a week to 10 days and then cleared. Apparently, the earth tremors caused grinding of the rocks along fractures, and the fine material so formed was picked up by ground water and discharged into the streams via springs. The northeastern part of the visible shore is submerged a foot or two; the southern part is in the zone of no change in shoreline between the submerged and emerged shorelines.

Mont. 22. Hebgen Lake earthquake: Red Canyon fault scarp cuts across Grayling Creek

County: Gallatin.
Lat 44°48′ N.; long 111°08′ W.
Number of photographs: 2.
Photograph scale: 1:10,000.
Focal length: 8.25 in.
Date flown: Aug. 22, 1959.
Map reference: U.S. Geol. Survey Tepee Creek 15-min quadrangle, scale 1:62,500.
Geology reference: Witkind, I. J., 1964, Reactivated faults north of Hebgen Lake: U.S. Geol Survey Prof. Paper 435–G, p. 37–50.

Features illustrated (set nos. Mont. 22 A–B in east corner of photographs.)—The Red Canyon fault scarp, 5–14 feet high, cuts across Grayling Creek near the center of photograph 22 B. Southeast of the creek the new fault scarp follows precisely an older fault scarp along the edge of a large alluvial fan. A higher, nearly parallel scarp may also have been produced by faulting. The main scarp northwest of the creek passes into many small fractures which continue the westward trend. The U.S. Geological Survey field camp is shown in a clump of aspens on a low hill northeast of the ranch. The white spots are house trailers, cars, and tents; dark areas are cloud shadows.

Nebr. 1. Changes in the channel of Sand Creek, 1939–54

County: Dawes.
Lat 42°47′ N.; long 103°26′ W.
Number of photographs: 4.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Sept. 9, 1939, and Aug. 8, 1954.
Map reference: U.S. Geol. Survey Alliance sheet, scale 1:250,000.
Geology reference: Schumm, S. A., 1961, Effect of sediment characteristics on erosion and deposition in ephemeral stream channels: U.S. Geol. Survey Prof. Paper 352–C, p. 41–49, figs. 23–27.

Features illustrated (set nos. Nebr. 1 A–D in northeast corner of photographs).—Historic changes in the Sand Creek channel, in part documented by these photographs, are discussed in detail by Schumm. Between 1939 and 1954, parts of the channel of Sand Creek have been completely filled by aggradation, and deposition has taken place on the adjacent flood plain. Elsewhere a trenched channel formed during this 15-year interval. There is also a noticeable difference in the growth of vegetation on surfaces of recent deposition.

Nebr. 2. Domical sand hills and saline lakes

County: Sheridan.
Lat 42°12′ N.; long 102°35′ W.
Number of photographs: 3.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Aug. 23, 1954.
Map reference: U.S. Geol. Survey Antioch 15-min quadrangle, scale 1:62,500.
Geology reference: Thorp, James, and Smith, H. T. U., 1952, Pleistocene eolian deposits of the United States, Alaska, and parts of Canada: Geol. Soc. America, map, scale 1:2,500,000. Smith, H. T. U., 1965, Dune morphology and chronology in central and western Nebraska: Jour. Geology, v. 73, p. 557–578.

Features illustrated (set nos. Nebr. 2 A–C in northeast corner of photographs).—Dome-shaped sandhills, largely stabilized by vegetation, have shallow northwest-trending grooves on their surfaces. Hills range from ½ to 1 mile in diameter and are surrounded by ephemeral saline lakes comparable in area to the sandhills.

Nebr. 3. Longitudinal sand ridges near Ashby

County: Grant.
Lat 42°01′ N.; long 101°57′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Aug. 16, 1955.
Map reference: U.S. Geol. Survey Ashby 15-min quadrangle, scale 1:62,500.
Geology reference: Thorp, James, and Smith, H. T. U., 1952, Pleistocene eolian deposits of the United States, Alaska, and parts of Canada: Geol. Soc. America, map, scale 1:2,500,000. Smith, H. T. U., 1965, Dune morphology and chronology in central and western Nebraska: Jour. Geology, v. 73, p. 557–578.

Features illustrated (set nos. Nebr. 3 A–B in northeast corner of photographs).—East-west trending sandhills rise from 150 to 200 feet above adjacent flat-floored valleys. On the crest of the ridges are many closed depressions and on the sides are small gullies. The surface is largely covered with turf except for a few gullies, at the mouths of which are small alluvial fans. Ashby is near the eastern edge of photograph 3 A.

Nebr. 4. Changes in channel of North Platte River, 1939–60

County: Garden.
Lat 41°24′ N.; long 102°26′ W.
Number of photographs: 6.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: July 12, 1939, and June 20, 1960.
Map reference: U.S. Geol. Survey Scottsbluff sheet, scale 1:250,000.

Features illustrated (set nos. Nebr. 4 A–E in northeast corner of photographs).—The flood plain of the river is about a mile wide and consists of many braided channels, some bare and some partly covered by low vegetation. A comparison of the flood plain as it was in 1939 with its picture in 1960 shows that during this 21-year interval some channels have been abandoned and a few new ones have formed. In general the main channels have not changed position, but they are narrower and islands have formed in them. In 1939 some of the small meandering gullies south of the river had conspicuous bare channels and bare alluvial fans on the edge of the main flood plain (for example in the southeast quadrant of photograph 4 D). In 1960 these same channels and fans appear to be narrower and in part covered by vegetation (S. A. Schumm, written commun., 1964).

Nebr. 5. Longitudinal dunes near Lone Valley

County: Logan.
Lat 41°37′ N.; long 100°38′ W.
Numerb of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Sept. 3, 1955.
Map reference: U.S. Geol. Survey Cody Lake 15-min quadrangle, scale 1:62,500.
Geology reference: Thorp, James, and Smith, H. T. U., 1952, Pleistocene eolian deposits of the United States, Alaska, and parts of Canada: Geol. Soc. America, map, scale 1:2,500,000. Smith, H. T. U., 1965, Dune morphology and chronology in central and western Nebraska: Jour. Geology, v. 73, p. 557–578.

Features illustrated (set nos. Nebr. 5 A–B in northeast corner of photographs).—Long narrow steep-sided and closely spaced sand ridges, commonly about 50 feet high are shown. These longitudinal dunes, largely stabilized by vegetation, are parallel or subparallel and, locally, branching. There are many small blowouts. The ridges appear to be superimposed on older, more or less stabilized, sandhills.

Nebr. 6. Longitudinal dunes on the north side of North Loup River

County: Loup.
Lat 41°45′ N.; long 99°18′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: July 10, 1954.
Map reference: U.S. Geol. Survey Taylor SE. and Sargent East 7½-min quadranges, scale 1:24,000.
Geology reference: Thorp, James, and Smith, H. T. U., 1952, Pleistocene eolian deposits of the United States, Alaska, and parts of Canada: Geol. Soc. America, map, scale 1:2,500,000. Smith, H. T. U., 1965, Dune morphology and chronology in central and western Nebraska: Jour. Geology, v. 73, p. 557–578.

Features illustrated (set nos. Nebr. 6 A–B in northeast corner of photographs).—The flood plain of North Loup River ranges from ½ to 1 mile wide; it is bordered on the north by large area of northwest-trending longitudinal dunes. Sandbars partly choke stream channels and cause incipient braided patterns. Dunes, largely stabilized by vegetation, are long, narrow, and steep sided and as much as 50 feet high. Dissected plains to the south of the river are mantled by a thick covering of loess.

Nev. 1. Lake Lahontan: Compound spit south of Bunejug Mountains

County: Churchill.
Lat 39°18′ N.; long 118°36′ W.
Number of photographs: 2.
Photograph scale: 1:43,200.
Focal length: 5.2 in.
Date flown: Dec. 18, 1947.
Map reference: U.S. Geol. Survey Carson Lake 15-min quadrangle, scale 1:62,500.
Geology reference: Morrison, R. B., 1964, Lake Lahontan: Geology of the southern Carson Desert, Nevada: U.S. Geol. Survey Prof. Paper 401, 156 p.; geol. map (pl. 3), scale 1:31,680. See figs. 11 and 25.

Features illustrated (set nos. Nev. 1 A–B in southeast corner of photographs).—Northeast of the alkali flat in the southwest quadrant of photograph 1 A (Bass Flats) is a spit nearly 2 miles long. The spit extends southeast from the southwest corner of the Bunejug Mountains which are circled by many higher Lahontan shorelines. The spit, mapped as part of the Pleistocene Sehoo Formation, is compound and has hooks graded to several successively lower lake levels. Recent eolian sand (Fallon Formation) extends across the southeast quadrant of photograph 1 B from the east edge of the alkali flat across Simpson Pass to Eightmile Flat.

Nev. 2. Lake Lahontan: Shorelines in southern Dead Camel Mountains

County: Churchill.
Lat 39°17′ N.; long 118°53′ W.
Number of photographs: 3.
Photograph scale: 1:43,200.
Focal length: 5.2 in.
Date flown: Dec. 18, 1947.
Map reference: U.S. Geol. Survey Fallon and Weber Reservoir 15-min quadrangles, scale 1:62,500.
Geology reference: Morrison, R. B., 1964, Lake Lahontan: Geology of the southern Carson Desert, Nevada: U.S. Geol. Survey Prof. Paper 401, 156 p.

Features illustrated (set nos. Nev. 2 A–C in southeast corner of photographs).—Isolated hills of volcanic rock in the southeast and west parts of photograph 2 B are fringed on their northeast sides by prominent shorelines of Pleistocene Lake Lahontan. Several conspicuous spits curve southward from the southeast corner of a hill near the center of the northwest quadrant of this photograph. (See Morrison, fig. 11A.) The coarse-grained sediments (gravel and sand) below the highest strand line have a smooth surface, whereas the fine-grained sediments (clay, silt, and some sand) are gullied. The curving line in the northeast quadrant is the trace of a possible fault. The adjacent light-colored material is lake sediment of Recent age.

Nev. 3. Lake Lahontan: Beaches at Sehoo Mountain

County: Churchill.
Lat 39°25′ N.; long 118°36′ W.
Number of photographs: 2.
Photograph scale: 1:43,200.
Focal length: 5.2 in.
Date flown: Dec. 18, 1947.
Map reference: U.S. Geol. Survey Carson Lake 15-min quadrangle, scale 1:62,500.
Geology reference: Morrison, R. B., 1964, Lake Lahontan: Geology of the southern Carson Desert, Nevada: U.S. Geol. Survey Prof. Paper 401, 156 p.; geol. map (pl. 3), scale 1:31,680. See fig. 10.

Features illustrated (set nos. Nev. 3 A–B in southeast corner of photographs).—The Pliocene basaltic rocks of Sehoo Mountain (southeast quadrant of photograph 3 B) are largely concealed beneath lacustrine and alluvial sediments of later Quaternary age. There is a marked contrast in minor topographic features above and below the highest shoreline (Lahontan beach) which lies about 450 feet above the lake plain to the west. More than 10 easily discernible shorelines are marked by wave-cut and depositional shore terraces, spits, bars, and tombolos. The shore features are contrasted with the multitude of large and small stream channels on the desert floor.

Nev. 4. Sand dunes near Fourmile Flat

County: Churchill.
Lat 39°16′ N.; long 118°28′ W.
Number of photographs: 2.
Photograph scale: 1:50,000.
Focal length: 6 in.
Date flown: Nov. 20, 1956.
Map reference: U.S. Geol. Survey Reno sheet, scale 1:250,000.
Geology reference: Morrison, R. B., 1964, Lake Lahontan: Geology of the southern Carson Desert, Nevada: U.S. Geol. Survey Prof. Paper 401, 156 p.; see pl. 1 and fig. 12A.

Features illustrated (set nos. Nev. 4 A–B in northeast corner of photographs).—Complex sandhills in the saddle at the south end of Stillwater Range northwest of the Sand Mountains. Sand appears to have come from the playa of Fourmile Flat to the southwest. The dunes extend northeastward to the divide. Small valleys choked by sand have now been partly re-excavated.

N.H. 1. Landslides in Franconia Notch

County: Grafton.
Lat 44°09′ N.; long 71°41′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: July 11, 1955.
Map reference: U.S. Geol. Survey Franconia 15-min quadrangle, scale 1:62,500.
Geology reference: Goldthwait, J. W., Goldthwait, Lawrence, and Goldthwait, R. P., 1951, The geology of New Hampshire; pt. 1, Surficial geology: New Hampshire State Plan. and Devel. Comm., p. 18, 54–55. Williams, C. R., and Billings, M. P., 1938, Petrology and structure of the Franconia quadrangle, New Hampshire: Geol. Soc. America Bull., v. 49, p. 1011–1044.

Features illustrated (set nos. N.H. 1 A–B in southeast corner of photographs).—This glacially scoured U-shaped drainage divide is carved in the Conway Granite. In 1948 a great landslide—debris avalanche—from Mount Lafayette (northeast quadrant of photograph 1 A) blocked the highway. Ancient forest-covered landslide scars are also visible. The "Old Man of the Mountain" (The Profile) is at the north end of the cliffs southwest of Profile Lake. Numerous ski trails in northwest quadrant of photograph 1 A are on Cannon (Profile) Mountain.

N.H. 2. Mount Pawtuckawny, a ring dike

County: Rockingham.
Lat 43°07′ N.; long 71°11′ W.
Number of photographs: 2.
Photograph scale: 1:34,000.
Focal length: 6 in.
Date flown: Apr. 30, 1951.
Map reference: U.S. Geol. Survey Mount Pawtuckaway 15-min quadrangle, scale 1:62,500.
Geology reference: Freedman, Jacob, 1950, Stratigraphy and structure of the Mount Pawtuckaway quadrangle, southeastern New Hampshire: Geol. Soc. America Bull., v. 61, p. 449–492.

Features illustrated (set nos. N.H. 2 A–B in northeast corner of photographs).—The Pawtuckaway mountains are a roughly circular group of hills about 2 miles in diameter that rise 300–500 feet above the surrounding lowlands. The mountains are composed dominantly of a core of dioritic rocks that underlie valleys surrounded by a ring dike of coarse-grained monzonite that forms the highest hills. The adjacent lowlands are underlain by quartz monzonite. The southwestern segment of the mountains is low because the ring dike is cut off along a northwest-trending high-angle fault.

N.J. 1. Outlier of Cohansey Sand

County: Burlington.
Lat 40°01′ N.; long 74°41′ W.
Number of photographs: 3.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Nov. 11, 1956.
Map reference: U.S. Geol. Survey Columbus 7½-min quadrangle, scale 1:24,000.
Geology reference: Owens, J. P., and Minard, J. P., 1962, Pre-Quaternary geology of the Columbus quadrangle, New Jersey: U.S. Geol. Survey Geol. Quad. Map GQ–160.

Features illustrated (set nos. N.J. 1 A–C in southeast corner of photographs).—Partly indurated rocks of late Tertiary age (Kirkwood Formation and Cohansey Sand) form steep-sided wooded hills that rise about 100 feet above a gently undulating cultivated plain formed on unconsolidated rocks of Late Cretaceous and early Tertiary age. The hills are outliers of clean quartz sand that forms well-drained soils. The plains are underlain by less well drained clayey glauconitic quartz sand.

N.J. 2. Shoreline changes at Little Egg Inlet, 1940–63

County: Atlantic.
Lat 39°29′ N.; long 74°19′ W.
Number of photographs: 3.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: 1940, 1957, 1963.
Map reference: U.S. Geol. Survey Atlantic City 15-min quadrangle, scale 1:62,500.

Features illustrated (set nos. N.J. 2 A–C in southeast corner of photographs).—These three photographs taken in 1940, 1957, and 1963 show changes in Island Beach south of the inlet but do not provide stereoscopic coverage. The tidal channels in the salt marsh serve as reference marks for comparison of shoreline changes from year to year. In 1940, a long narrow north-trending beach and spit separated the marsh from the ocean. By 1957, the north-trending beach and spit had been replaced by a northwest-trending beach and spit, shorter and slightly west of those of 1940. In addition a new northwest-curving spit about a quarter of a mile wide had been built east of the position of the 1940 spit and extending northward for about a mile. By 1963, the curving spit had grown northwestward an additional 1,000 feet and changed shape to some extent.

N. Mex. 1. Sandstone cuestas near Ship Rock

County: San Juan.
Lat 36°41′ N.; long 108°50′ W.
Number of photographs: 4.
Photograph scale: 1:54,000.
Focal length: 6 in.
Date flown: Feb. 5, 1954.
Map reference: U.S. Geol. Survey Ship Rock 15-min quadrangle, scale 1:62,500.
Geology reference: O'Sullivan, R. B., and Beikman, H. M., 1963, Geology, structure, and uranium deposits of the Ship Rock quadrangle, New Mexico and Arizona: U.S. Geol. Survey Misc. Geol. Inv. Map I–345 (sheet 1, Geology).

Features illustrated (set nos. N. Mex. 1 A–D in northeast corner of photographs).—This impressive volcanic neck, more than 1,500 feet high, and its radiating dikes stand on a pedestal of virtually flat-lying Mancos Shale. A small dark-colored apron of waste surrounds the neck; farther away the shale of the pedestal is scored by many small closely spaced radial stream channels (high drainage density). The large north-draining wash in the eastern half of photograph 1 A (Little Ship Rock Wash) follows a strike valley in Mancos Shale. The cuesta just east of the wash is the Gallup Sandstone, which here occurs within the Mancos Shale. West of the wash is a group of discontinuous cuestas and hills that are eastward-dipping beds of sandstone separated by shale and siltstone (Dakota Sandstone and Morrison Formation).

N. Mex. 2. Landslides from Black Mesa near Lyden

County: Rio Arriba.
Lat 36°09′ N.; long 106°01′ W.
Number of photographs: 2.
Photograph scale: 1:21,000.
Focal length: 6 in.
Date flown: Dec. 2, 1949.
Map reference: U.S. Geol. Survey Lyden and Velarde 7½-min quadrangles, scale 1:24,000.
Geology reference: Miller, J. P., Montgomery, Arthur, and Sutherland, P. K., 1963, Geology of part of the southern Sangre de Cristo Mountains, New Mexico: New Mexico Bur. Mines and Mineral Resources Mem. 11, 106 p.

Features illustrated (set nos. N. Mex. 2 A–B in northeast corner of photographs).—The lava flows of Black Mesa rest on semiconsolidated sediments of late Cenozoic age. Semicircular and rectangular landslide blocks mantle the southeast side of the mesa. The caprock near the edge of the mesa is broken by conspicuous cracks that parallel the top of the scarp. The landsliding is related to the removal of material by the lateral swing of the Rio Grande across its flood plain, here as much as three-quarters of a mile wide. Southeast of the river the edge of a dissected pediment is outlined by an irrigation ditch.

N. Mex. 3. Landslides in Rio Grande Canyon near Embudo

County: Rio Arriba and Taos.
Lat 36°13′ N.; long 105°55′ W.
Number of photographs: 2.
Photograph scale: 1:37,600.
Focal length: 6 in.
Date flown: July 23, 1958.
Map reference: U.S. Geol. Survey Velarde and Taos Junction 7½-min quadrangles, scale 1:24,000.
Geology reference: Miller, J. P., Montgomery, Arthur, and Sutherland, P. K., 1963, Geology of part of the southern Sangre de Cristo Mountains, New Mexico: New Mexico Bur. Mines and Mineral Resources Mem. 11, 106 p.; geol. map (pl. 1), scale 1:63,360.

Features illustrated (set nos. N. Mex. 3 A–B in northeast corner of photographs).—Semiconsolidated sediments of later Cenozoic age (silt, sand, gravel, and a little ash, clay, and breccia) capped by basalt flows (north half of photograph 3 A) have been dissected to depths of about 1,000 feet. Tilted landslide blocks of the caprock mantle the canyon walls. On the north side of the river (northwest quadrant of photograph 3 B), landsliding has removed all the caprock from a part of the top of the canyon wall near Chorreras. This loss of caprock has exposed the light-colored sedimentary rocks and left only slump blocks of lava on the walls below. There is no evidence that any large-scale movement has taken place for a long time.

N. Mex. 4. Lava flows and intrusives near Philmont Scout Ranch

County: Colfax.
Lat 36°27′ N.; long 104°59′ W.
Number of photographs: 3.
Photograph scale: 1:28,400.
Focal length: 6 in.
Date flown: Sept. 18, 1954.
Map reference: U.S. Geol. Survey Miami and Tooth of Time 15-min quadrangles, scale 1:62,500.
Geology reference: Robinson, G. D., Wanek, A. A., Hays, W. H., and McCallum, M. E., 1964, Philmont Country: The rocks and landscape of a famous New Mexico Ranch: U.S. Geol. Survey Prof. Paper 505, 152 p.; geol. map (pl. 3), scale 1:48,000.

Features illustrated (set nos. N. Mex. 4 A–C in southeast corner of photographs).—The creek that flows in a northeasterly direction across photograph 4 B (Urraca Creek) is bordered in the northeast quadrant by lowlands floored with shale thinly veneered by alluvium. Philmont Scout Ranch is in the northeast corner of this photograph. A gravel terrace about 150 feet high (northeast corner of photograph 4 A) is a remnant of an ancient flood plain of Urraca Creek. The steep-sided ridge of dacite porphyry northwest of the creek is part of a laccolith intruded in the adjacent shale of Cretaceous age. The lower contact of the intrusive body is largely concealed by colluvium, except near the west edge of the photograph where the base of the the laccolith is marked by a sharp break in slope. The slopes of the basalt-capped mesa in the southwest corner of this same exposure (Urraca Mesa) are mantled by landslide deposits, except near the east edge of the photograph where the underlying Cretaceous shale is exposed in gullies (tributary to Chicoso Creek).

N. Mex. 5. Mount Capulin, a scoria cone

County: Union.
Lat 36°46′ N.; long 103°58′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: July 27, 1956.
Map reference: U.S. Geol. Survey Dalhart sheet, scale 1:250,000.
Geology reference: Collins, R. F., 1949, Volcanic rocks of northeastern New Mexico: Geol. Soc. America Bull., v. 60, no. 6, p. 1017–1040.

Features illustrated (set nos. N. Mex. 5 A–B in southeast corner of photographs).—An almost undissected scoria volcano about 1,000 feet high which has an unbreached crater about 100 feet deep. The cone is surrounded by older weathered basalt flows that still retain much of their initial surface form. The cone is a National Monument. Drainage is radial.

N. Mex. 6. Rhyolite lava dome and flows in Valles Caldera

County: Sandoval.
Lat 35°50′ N.; long 106°31′ W.
Number of photographs: 3.
Photograph scale: 1:32,680.
Date flown: 1935.
Map reference: U.S. Geol. Survey Jemez Springs and Frijoles 15-min quadrangles, scale 1:62,500.
Geology reference: Smith, R. L., Bailey, R. A., and Ross, C. S., 1961, Structural evolution of the Valles Caldera, New Mexico, and its bearing on the emplacement of ring dikes, *in* Short papers in the geologic and hydrologic sciences: U.S. Geol. Survey Prof. Paper 424–D, p. D145–D149; geol. map (fig. 340.1), scale 1:139,000.

Features illustrated (set nos. N. Mex. 6 A–C in southeast corner of photographs).—The broad elongate mountain near the center of photograph 6 B is one of 10 similar rhyolite dome-flows that form a discontinuous ring within the Valles Caldera in the Jemez Mountains. The conspicuous arcuate ridges on the south side of the mountain are ribs of vertically flow-banded rhyolite which have been accentuated by erosion of intervening zones of less resistant flow breccia. These semiconcentric ridges are part of a thick rhyolite flow that forms the base of the dome-flow complex and extends 8 miles to the west (beyond the limits of the photograph). Capping this basal flow is another dome-flow which originates at the grass-covered crest and extends 2 miles to the northeast; this uppermost flow also displays conspicuous concentric flow ridges. The small tree-covered knoll immediately northeast of the dome-flow complex is a small isolated rhyolite dome.

N. Mex. 7. Fine-textured topography on upper Tertiary sediments

County: Santa Fe and Los Alamos.
Lat 35°47′ N.; long 106°07′ W.
Number of photographs: 2.
Photograph scale: 1:54,000.
Focal length: 6 in.
Date flown: May 27, 1954.
Map reference: U.S. Geol. Survey Espanola 15-min quadrangle, scale 1:62,500.
Geology reference: Griggs, R. L., 1964, Geology and groundwater resources of Los Alamos area, New Mexico: U.S. Geol. Survey Water-Supply Paper 1753, 107 p.

Features illustrated (set nos. N. Mex. 7 A–B in northeast corner of photographs).—Fine-textured topography with high drainage density formed on the semiconsolidated upper Tertiary rocks (sandstone, conglomerate, siltstone, and clay of the Santa Fe Group). The drainage pattern is largely dendritic, except for the parallel or pinnate pattern in the northeast quadrant of photograph 7 B. Mesas near the west edge of the same photograph are capped by basaltic rocks of late Tertiary or Quaternary age. Buckman is near the northwest corner of photograph 7 B.

N. Mex. 8. Normal faults cutting basalt mesa

County: Sandoval.
Lat 35°26′ N.; long 106°32′ W.
Number of photographs: 4.
Photograph scale: 1:31,680.
Date flown: 1935.
Map reference: U.S. Geol. Survey Santa Ana Pueblo 7½-min quadrangle, scale 1:24,000.
Geology reference: Kelley, V. C., 1954, Tectonic map of a part of the upper Rio Grande area, New Mexico: U.S. Geol. Survey Oil and Gas Inv. Map OM–157, scale 1:190,080.

Features illustrated (set nos. N. Mex. 8 A–D in southeast corner of photographs).—The photographs show the eastern half of the Santa Ana mesa near the confluence of Jemez River and Rio Grande (photograph 8 A). The basalt flows issued from a north-south-trending string of vents, some of which are visible on the west edge of photographs 8 C and 8 D, and also from a similar line of vents outside the area shown to the east. Numerous north-south-trending faults displace the basalts from a few to 150 feet. The blocks are tilted eastward, and along any one fault the eastern block has risen relative to the one to the west. The drainage of the mesa has a trellis pattern.

N. Mex. 9. Fault border of Rio Grande depression along Arroyo Tonque

County: Sandoval.
Lat 35°22′ N.; long 106°22′ W.
Number of photographs: 3.
Photograph scale: 1:54,000.
Focal length: 6 in.
Date flown: Feb. 28, 1954.
Map reference: U.S. Geol. Survey San Felipe Pueblo 15-min quadrangle, scale 1:62,500.
Geology reference: Stearns, C. E., 1953, Tertiary geology of the Galisteo-Tonque area, New Mexico: Geol. Soc. America Bull., v. 64, p. 459–508; geol. map (pl. 1), scale 1:125,000.

Features illustrated (set nos. N. Mex. 9 A–C in northeast corner of photographs).—Unconsolidated or weakly cemented alluvial-fan deposits of late Tertiary age (western part of photograph 9 B) are downfaulted against the east-dipping Paleozoic to early Tertiary strata. A dendritic drainage pattern and a high drainage density characterize the areas underlain by late Tertiary rocks. Hogbacks of pre-Tertiary rock are offset along high-angle faults and are broken by crosscutting dikes (southeast quadrant of photograph 9 B). Small flat surfaces now dissected are remnants of gravel deposits resting unconformably on the underlying deformed rocks. These unconformities are largely small pediment surfaces. Several of the formations in, and structures of, the older rocks, mapped by Stearns (pl. 1), can be traced on these photographs.

N. Mex. 10. Flows, dikes, and unconformities in the Galisteo area

County: Santa Fe and Sandoval.
Lat 35°31′ N., long 106°12′ W.
Number of photographs: 3.
Photograph scale: 1:54,000.
Focal length: 6 in.
Date flown: Feb. 28, 1954.
Map reference: U.S. Geol. Survey Agua Fria, Santo Domingo Pueblo, and San Felipe Pueblo 15-min quadrangles, scale 1:62,500.
Geology reference: Stearns, C. E., 1953, Tertiary geology of the Galisteo-Tonque area, New Mexico: Geol. Soc. America Bull., v. 64, p. 459–508; see pl. 1.

Features illustrated (set nos. N. Mex. 10 A–C in northeast corner of photographs).—The Pleistocene(?) lava flows and cinder cone of the Mesita de Juana Lopez (northeast quadrant of photograph 10 B) rest on slightly deformed upper Tertiary sediments and volcanics (northwest quadrant) and on eastward-dipping upper Paleozoic and Mesozoic sedimentary rocks (near the center of same photograph). The Tertiary rocks are downfaulted against the older sedimentary rocks. Crosscutting dikes are conspicuous in the pre-Tertiary rocks (southeast quadrant of photograph 10 B). Stippled and linear patterns of dots which are conspicuous on Mesita de Juana Lopez resemble those found on basalt in the Snake River Plains and are attributed to Pleistocene frost action.

N. Mex. 11. Patterned ground on basalt mesas near Laguna

County: Valencia.
Lat 35°03′ N.; long 107°27′ W.
Number of photographs: 2.
Photograph scale: 1:37,400.
Focal length: 6 in.
Date flown: May 29, 1955.
Map reference: U.S. Geol. Survey Laguna 7½-min quadrangle, scale 1:24,000.
Geology reference: Malde, H. E., 1964, Patterned ground in the western Snake River Plain, Idaho, and its possible cold climate origin: Geol. Soc. America Bull., v. 75, p. 191–208. Moench, R. H., 1963, Geologic map of the Laguna quadrangle, New Mexico: U.S. Geol. Survey Geol. Quad. Map GQ–208.

Features illustrated (set nos. N. Mex. 11 A–B in northeast corner of photographs).—Basalt-capped mesas (northeast quadrant of photograph 11 A), standing about 700 feet above the Rio San Jose to the south, show stippled and linear patterns of silt mounds that are possibly of cold-climate origin. (See Idaho 2 and 3.) These lower Pleistocene(?) basalt flows came from Wheat Mountain just north of the area shown in the photographs.

Talus and landslide deposits, largely basalt rubble, mantle the slopes of the mesas where the basalt rests on Mancos Shale overlying Dakota Sandstone and Morrison Formation.

N. Mex. 12. Travertine mesa along Comanche thrust fault

County: Valencia and Socorro.
Lat 34°35′ N.; long 107°12′ W.
Number of photographs: 3.
Photograph scale: 1:28,400.
Focal length: 6 in.
Date flown: Oct. 12, 1951.
Map reference: U.S. Geol. Survey Mesa Aparejo 15-min quadrangle, scale 1:62,500.
Geology reference: Kelley, V. C., and Wood, G. H., 1946, Geologic map of the Lucero uplift, Valencia, Socorro, and Bernalillo Counties, New Mexico: U.S. Geol. Survey Oil and Gas Inv. Prelim. Map 47.

Features illustrated (set nos. N. Mex. 12 A–C in southeast corner of photographs).—Plains near the western edge of the valley of the Rio Puerco (eastern part of photograph 12 B), formed largely of gravel on pediment surfaces, adjoin a cuesta formed of westward-dipping Pennsylvanian limestones brought up along the westward-dipping Comanche thrust fault. Travertine deposited from springs along the thrust fault forms a low dissected mesa (light-colored area on photograph), through which Arroyo Pato has cut a gorge (northeast quadrant of same photograph). The springs are now largely inactive, and the travertine is concealed beneath open woodlands (piñon and juniper).

N.Y. 1. Niagara cuesta at Lewiston

County: Niagara.
Lat 43°10′ N.; long 79°03′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Sept. 25, 1938.
Map reference: U.S. Geol. Survey Lewiston 7½-min quadrangle, scale 1:24,000 (N.Y. only), Toronto sheet, scale 1:250,000.
Geology reference: Johnston, R. H., 1964, Ground water in the Niagara Falls area, New York, with emphasis on the water-bearing characteristics of the bedrock: New York Water Resources Comm. Bull. GW–53, 93 p.

Features illustrated (set nos. N.Y. 1 A–B in southeast corner of photographs).—The Niagara River emerges from a narrow gorge cut about 250 feet into a flat upland and enters a broad flat lowland where its channel is wide and its banks are low. The north-facing escarpment separating the upland from the lowland is the Niagara cuesta, across which the ancestral Niagara River flowed in late-glacial time as a waterfall that has now retreated southward about 6½ miles. The upper part of the escarpment is the massive Lockport Dolomite, underlain by the Rochester Shale and older rocks that erode by sapping. This sapping causes the dolomite cap to be undermined. The lowland north of the escarpment is underlain by Queenston Shale.

N.Y. 2. Niagara Falls

County: Niagara.
Lat 43°05′ N.; long 79°04′ W.
Number of photographs: 2.
Photograph scale: 1:24,000.
Focal length: 6 in.
Date flown: May 7, 1963.
Map reference: U.S. Geol. Survey Niagara Falls 7½-min quadrangle, scale 1:24,000.
Geology reference: Johnston, R. H., 1964, Ground water in the Niagara Falls area, New York, with emphasis on the water-bearing characteristics of the bedrock: New York Water Resources Comm. Bull. GW–53, 93 p.

Features illustrated (set nos. N.Y. 2 A–B in southeast corner of photographs).—Horseshoe Falls and American Falls separated by Goat Island. The falls are about 160 feet high. At the time these photographs were taken, there was considerable ice in the rapids both above and below the falls. The massive Lockport Dolomite forms the lip of the falls and the upper part of the walls of the gorge. Below is the Rochester Shale.

N.Y. 3. Drumlins near Palmyra

County: Wayne.
Lat 43°08′ N.; long 77°14′ W.
Number of photographs: 2.

Photograph scale: 1:60,000.
Focal length: 6 in.
Date flown: May 6, 1960.
Map reference: U.S. Geol. Survey Palmyra and Macedon 15-min quadrangles, scale 1:62,500; Ontario, Williamson, Macedon, and Palmyra 7½-min quadrangles, scale 1:24,000.
Geology reference: Fairchild, H. L., 1929, New York drumlins: Rochester Acad. Sci. Proc., v. 7, 37 p.

Features illustrated (set nos. N.Y. 3 A–B in northeast corner of photographs).—Ice moving southward from the Ontario basin formed a large drumlin field on the Ontario plain north of the Finger Lakes. The bedrock, concealed beneath drift, is in large part gently dipping shale and dolomite of Silurian age. The drumlins are oval in plan and range in length from less than a quarter of a mile to more than 2 miles. They are commonly three to five times longer than they are wide. The flat-floored valleys between the drumlins are underlain in part by lake deposits and in part by glacial outwash.

N.Y. 4. Potsdam outliers near Hammond

County: St. Lawrence and Jefferson.
Lat 44°22′ N.; long 75°46′ W.
Number of photographs: 3.
Photograph scale: 1:19,000.
Focal length: 6 in.
Date flown: May 4, 1960.
Map reference: U.S. Geol. Survey Muskellunge Lake, Hammond, Redwood, and Chippewa Bay 7½-min quadrangles, scale 1:24,000.
Geology reference: New York State Museum and Science Service, Geological Survey, 1962, Geologic map of New York, 1961. Adirondack sheet: New York State Mus. and Sci. Service Geol. Survey Map and Chart Ser. 5, scale 1:250,000.

Features illustrated (set nos. N.Y. 4 A–C in northeast corner of photographs).—Broad tables of flat-lying Potsdam Sandstone of Late Cambrian age rise above lowlands underlain by metasedimentary rocks of Precambrian age. The mantle of glacial drift is thin and patchy, and the grain of the metamorphic rocks is clearly expressed by the irregular shapes of the small hills east of Black Creek.

N.Y. 5. Hickory Lake phacolith

County: St. Lawrence.
Lat 44°26′ N.; long 75°35′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 6 in.
Date flown: May 4, 1960.
Map reference: U.S. Geol. Survey Pope Mills 7½-min quadrangle, scale 1:24,000.
Geology reference: Buddington, A. F., 1934, Geology and mineral resources of the Hammond, Antwerp, and Lowville quadrangles: New York State Mus. Bull. 296, 251 p.; geol. map, scale 1:62,500.

Features illustrated (set nos. N.Y. 5 A–B in northeast corner of photographs).—The oval-shaped area of numerous small roughly concentric ridges in the southern half of photograph 5 B is one of Buddington's granite phacoliths. Although the area has been glaciated, the drift is thin and discontinuous. The lowland that surrounds the phacolith (along Birch Creek) is mantled by fine-grained lake sediments of Quaternary age. The surrounding area of more irregular hills is underlain by quartzite, marble, gneiss, and related rocks of the Grenville Series.

N.Y. 6. Deltas of Ausable River

County: Clinton and Essex.
Lat 44°34′ N.; long 73°27′ W.
Number of photographs: 5.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: June 28, 1962.
Map reference: U.S. Geol. Survey Plattsburgh 15-min quadrangle, scale 1:62,500.
Geology reference: Chapman, D. H., 1937, Late-glacial and postglacial history of the Champlain Valley: Am. Jour. Sci., 5th ser., v. 34, no. 200, p. 89–124.

Features illustrated (set nos. N.Y. 6 A–E in southeast corner of photographs).—Beaches, spits, and underwater features near the mouths of two distributaries of the Ausable River delta in Lake Champlain (photograph 6 D) show both north and south transport of sediment along the lakeshore. Remnants of ancient Ausable River deltas occur nearby. The south edge of a high delta is south of the curving east-west road just north of the center of photograph 6 A. At a somewhat lower level, the Ausable River followed a curving channel similar to those on the modern delta that can be seen in the southwest quadrant of photograph 6 D between the river and the main north-south highway. Another channel follows the curving north edge of the high delta from the main highway (in northwest quadrant of photograph 6 B) southeastward through the center of photograph where the channel turns northeastward into the swamp that empties into the lake. Bedrock is exposed in places on the north side of this channel which appears to have discharged into the lake at or below present lake level. Ausable Chasm is just visible on the west edge of photograph 6 B.

N.C. 1. Changes in Hatteras Inlet caused by Hurricane Helene, September 1958

County: Hyde and Dare.
Lat 35°12′ N.; long 75°45′ W.
Number of photographs: 6.
Photograph scale: 1:20,000, 1955; 1:24,000, 1959.
Date flown: Mar. 29, 1955, Aug. 16, 1959.
Map reference: U.S. Geol. Survey Green Island and Hatteras 7½-min quadrangles, scale 1:24,000.

Features illustrated (set nos. N.C. 1 A–F in southwest corner of photographs).—On the east side of Hatteras

Inlet (east of center of photograph 1 B), the 1955 photographs show a curved spit (Inlet Peninsula) separated from the west end of Hatteras Island (west edge of same photograph) by a sand flat. Near the center of the inlet is Pelican Shoal (just north of center of same photograph). The barrier beach on the west side of the inlet (Ocracoke Island) is bisected by a narrow channel just east of the Coast Guard station (near center of photograph 1 A). The 1959 photographs, taken nearly a year after the hurricane, show that the narrow channel just east of the site of the station has been greatly enlarged, the station is gone, and Pelican Shoal is connected to a remnant of the east end of Ocracoke Island. The tidal delta on the north (lagoon) side of the inlet is well shown in the 1959 photographs. Deposition on the south (ocean) side of the inlet is shown by underwater bars and by curved spits on the south side of Pelican Shoal and the isolated tip of Ocracoke Island (M. T. El-Ashry, written commun., 1963).

N.C. 2. Shoreline changes at Cape Hatteras, 1945–62

County: Dare.
Lat 35°14′ N.; long 75°32′ W.
Number of photographs: 4.
Photograph scale: 1:21,000, 1945, 1953; 1:24,000, 1959, 1962.
Date flown: 1945, 1953, 1959, 1962.
Map reference: U.S. Geol. Survey Cape Hatteras 7½-min quadrangle, scale 1:24,000.
Geology reference: Athearn, W. D., and Ronne, Claude, 1953, Shoreline changes at Cape Hatteras: Naval Research Rev., v. 16, no. 6, p. 17–24.

Features illustrated.—These photographs do not provide stereoscopic coverage. On the 1945 photograph (*set no. N.C. 2 A in the southeast corner*) a dirt road (white line) runs north from the Cape to the center point on the north edge. A point common to all the photographs is the small light-colored area of bare sand about 0.1 of an inch long that lies just west of the road and about 1.5 inches north of the shore.

The 1953 photograph (*set no. N.C. 2 B in the northwest corner*) shows that the erosion of the beach southwest of the reference point (*set no. N.C. 2 C in the southwest corner*) amounted to about 1,500 feet during an 8-year period. The 1959 photograph shows further erosion from 1953 to 1959, but the 1962 photograph (*set no. N.C. 2 D in the southeast corner*) suggests very little change from 1959 to 1962.

The spit at the tip of the Cape has changed markedly during this 17-year period. In 1945 there was almost no spit, in 1953 a prominent spit pointed eastward, and in 1959 no spit was visible.

M. T. El-Ashry suggests (written commun., 1963) that the southwest-trending spit in the 1962 photograph was formed during an extratropical cyclone that passed over the area a few days before the photograph was taken. A similar spit formed during Hurricane Helene in 1958 but had disappeared by the time the 1959 photograph was taken.

N. Dak. 1. Fluted drift near Long Lake Creek

County: Emmons.
Lat 46°28′ N.; long 100°01′ W.
Number of photographs: 2.
Photograph scale: 1:60,000.
Focal length: 6 in.
Date flown: July 28, 1952.
Map reference: U.S. Geol. Survey Jamestown and Bismarck sheets, scale 1:250,000.
Geology reference: Colton, R. B., Lemke, R. W., and Lindvall, R. M., 1963, Preliminary glacial map of North Dakota: U.S. Geol. Survey Misc. Geol. Inv. Map I–331. Fisher, S. P., Jr., 1952, The geology of Emmons County, North Dakota: North Dakota Geol. Survey Bull. 26, 47 p.

Features illustrated (set nos. N. Dak. 1 A–B in northeast corner of photographs).—Plains are mantled by ground moraine. On the west side of Long Lake Creek (west half of photograph 1 A), the ground surface was molded by south-southwest-moving ice into linear ridges and swales that give a fluted appearance to the surface.

N. Dak. 2. End moraines in Kidder County

County: Kidder.
Lat 47°15′ N.; long 99°35′ W.
Number of photographs: 3.
Photograph scale: 1:60,000.
Focal length: 6 in.
Date flown: July 31, 1952.
Map reference: U.S. Geol. Survey New Rockford sheet, scale 1:250,000.
Geology reference: Colton, R. B., Lemke, R. W., and Lindvall, R. M., 1963, Preliminary glacial map of North Dakota: U.S. Geol. Survey Misc. Geol. Inv. Map I–331. Laird, W. M., Lemke, R. W., and Hansen, Miller, 1958, Guidebook, Midwestern Friends of the Pleistocene, 9th Annual Field Conference, 1958: North Dakota Geol. Survey Misc. Ser. 10, 114 p.

Features illustrated (set nos. N. Dak. 2 A–C in northeast corner of photographs).—A broad area of collapse or "dead ice" ground moraine is characterized by many large and small lakes. There is no conspicuous linear trend to the topography. A prominent belt of end moraine (north half of photograph 2 B) formed by southward-moving ice shows many small subparallel linear ridges and swales with a few small ponds. A part of an older belt of more lobate end moraine also built by southward-moving ice occurs in the southern part of the photographs. These moraines are the northward extension of the Streeter moraine that Lemke and Colton believe marks the drift border of an ice advance that is younger than the Cary maximum.

N. Dak. 3. Streeter moraine near Alkaline Lake

County: Kidder, Stutsman, and Logan.
Lat 46°38′ N.; long 99°25′ W.
Number of photographs: 2.
Photograph scale: 1:60,000.
Focal length: 6 in.
Date flown: July 28, 1952.
Map reference: U.S. Geol. Survey Jamestown sheet, scale 1:250,000.
Geology reference: Colton, R. B., Lemke, R. W., and Lindvall, R. M., 1963, Preliminary glacial map of North Dakota: U.S. Geol. Survey Misc. Inv. Map I-331. Paulson, G. F., 1952, Geology and occurrence of ground water in the Streeter area, Stutsman, Logan, and Kidder Counties, North Dakota: North Dakota Geol. Survey Ground-Water Studies 20, 73 p.

Features illustrated (set nos. N. Dak. 3 A–B in northeast corner of photographs).—The massive Streeter moraine with many prominent arcuate ridges (southwest quadrant of photograph 3 B) was built by southwest-moving glacier ice. In front of it is an outwash plain. Behind the moraine to the northeast is a broad area of collapse moraine deposits with some large lakes and multitudes of small irregularly shaped ponds and swamps.

N. Dak. 4. Lake Agassiz: Beaches and dissected lake floor near Larimore

County: Grand Forks.
Lat 47°56′ N.; long 97°36′ W.
Number of photographs: 2.
Photograph scale: 1:60,000.
Focal length: 6 in.
Date flown: Sept. 10, 1952.
Map reference: U.S. Geol. Survey Larimore 15-min quadrangle, scale 1:62,500.
Geology reference: Colton, R. B., Lemke, R. W., and Lindvall, R. M., 1963, Preliminary glacial map of North Dakota: U.S. Geol. Survey Misc. Geol. Inv. Map I-331. Laird, W. M., Lemke, R. W., and Hansen, Miller, 1958, Guidebook, Midwestern Friends of the Pleistocene, 9th Annual Field Conference, 1958: North Dakota Geol. Survey Misc. Ser. 10, 114 p.

Features illustrated (set nos. N. Dak. 4 A–B in northeast corner of photographs).—Prominent beaches (Campbell, McCauleyville, Hillsboro) cross the northeast-sloping floor of the lake basin. The meandering Turtle River has carved a narrow valley about 50 feet below the lake floor. It flows in part parallel to the beach ridges and in part at right angles to them.

N. Dak. 5. Lake Agassiz: Herman Beach on west edge of lake basin near Kempton

County: Grand Forks.
Lat 47°52′ N.; long 97°40′ W.
Number of photographs: 2.
Photograph scale: 1:60,000.
Focal length: 6 in.
Date flown: Aug. 1, 1952.
Map reference: U.S. Geol. Survey Larimore 15-min quadrangle, scale 1:62,500.
Geology reference: Colton, R. B., Lemke, R. W., and Lindvall, R. M., 1963, Preliminary glacial map of North Dakota: U.S. Geol. Survey Misc. Geol. Inv. Map I-331. Upham, Warren, 1895, The Glacial Lake Agassiz: U.S. Geol. Survey Mon. 25, p. 332–333. (Out of print.)

Features illustrated (set nos. N. Dak. 5 A–B in northeast corner of photographs).—Herman beach, which marks the western limit of Lake Agassiz, separates the smooth lake plain on the east from an area of ground moraine to the west. In the southeast quadrant of photograph 5 B, the Herman beach is a ridge of sand and gravel with undrained depressions to the west as much as 15 feet deep. The ridge is virtually continuous except where crossed by Little Goose River. In areas farther north, the local drainage from the till plain to the west is deflected north or south by the beach ridge.

N. Dak. 6. Lake Agassiz: Beaches and wave-cut scarp near Arvilla

County: Grand Forks.
Lat 47°53′ N.; long 97°27′ W.
Number of photographs: 3.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: June 24, 1962.
Map reference: U.S. Geol. Survey Emerado 15-min quadrangle, scale 1:62,500.
Geology reference: Upham, Warren, 1895, The Glacial Lake Agassiz: U.S. Geol. Survey Mon. 25, p. 418, 436, pl. 29 and fig. 25.

Features illustrated (set nos. N. Dak. 6 A–C in northeast corner of photographs).—Prominent northwest-trending gravelly beach ridges as much as 1,000 feet wide are locally the sites of borrow pits. On the lake (east) side, the beaches are about 20 feet high; on the landward (west) side they are as much as 10 feet high. The McCauleyville beach passes through the center of photograph 6 C, and the Campbell beach is just to the west. West of the latter beach is a low wave-cut(?) scarp. The trellised drainage pattern is controlled by the ridges.

Ohio 1. Pleistocene lake beaches east of Elyria

County: Lorain.
Lat 41°25′ N.; long 82°03′ W.
Number of photographs: 3.
Photograph scale: 1:60,000.
Focal length: 6 in.
Date flown: May 16, 1960.
Map reference: U.S. Geol. Survey Avon and North Olmsted 7½-min quadrangles, scale 1:24,000. Toledo sheet, scale 1:250,000.
Geology reference: Goldthwait, R. P., White, G. W., and Forsyth, J. L., 1961, Glacial map of Ohio: U.S. Geol. Survey Misc. Geol. Inv. Map. I-316.

Features illustrated (set nos. Ohio 1 A–C in northeast corner of photographs).—On the lacustrine plain south of Lake Erie the main highways follow sandy and gravelly beach ridges of Wisconsin age. A major highway (State Route 254) enters the west edge of photograph 1 B just north of center and follows the gently curving beaches of Lake Warren northeast to Avon (about 1 in. south of center of north edge of photograph) and thence east beyond the limits of this exposure. Another main road (U.S. Route 20) enters the west edge of photograph 1 B about 3 inches south of the center point, and follows the Lake Whittlesey beach to the northeast, under the Ohio Turnpike, through North Ridgeville, and on the northwest side of an area of woodland (due east of center of photograph).

Okla. 1. Cuesta and strip mine near Lehigh

County: Coal.
Lat 34°26′ N.; long 96°12′ W.
Number of photographs: 3.
Photograph scale: 1:17,000.
Focal length: 6 in.
Date flown: Mar. 4, 1956.
Map reference: U.S. Geol. Survey Lehigh 7½-min quadrangle, scale 1:24,000.
Geology reference: Knechtel, M. M., 1937, Geology and fuel resources of the southern part of the Oklahoma coal field; pt. 2, The Lehigh district, Coal, Atoka, and Pittsburg Counties: U.S. Geol. Survey Bull. 874–B, p. 91–149; geol. map (pl. 11), scale 1:63,360.

Features illustrated (set nos. Okla. 1 A–C in northeast corner of photographs).—A sequence of shale, sandstone, and coal of Pennsylvanian age dips gently northeast at about 400 feet to the mile. A sandstone cuesta from 40 to 80 feet high faces southwest. The dip slope to the northeast is wooded. The strip mine on the cultivated plain west of the cuesta has been opened along the Lehigh coal bed of the McAlester Shale.

Okla. 2. Sigmoid fold in Black Knob Ridge

County: Atoka.
Lat 34°24′ N.; long 96°05′ W.
Number of photographs: 3.
Photograph scale: 1:17,000.
Focal length: 6 in.
Date flown: Feb. 29, 1956.
Map reference: U.S. Geol. Survey Stringtown 7½-min quadrangle, scale 1:24,000.
Geology reference: Hendricks, T. A., 1947, Geology of the western part of the Ouachita Mountains in Oklahoma: U.S. Geol. Survey Oil and Gas Inv. Prelim. Map 66, sheet 1, scale 1:42,240.

Features illustrated (set nos. Okla. 2 A–C in northeast corner of photographs).—An S-shaped line of hills rises about 100–160 feet above the surrounding shale lowland. The hills are divisible into two ridges. The western one is the higher of the two and is held up by the Bigfork Chert; the eastern one is composed of Arkansas Novaculite. Shale units (Polk Creek Shale and Missouri Mountain Shale) separate the two ridges. The rocks are tightly folded. The pond is on the axis of a northeast-plunging syncline; to the southeast is an anticline plunging in the same direction. These ridges are part of a narrow structural block bounded by thrust faults that are not visible in these photographs.

Okla. 3. Pine Mountain syncline

County: Le Flore.
Lat 34°55′ N.; long 94°40′ W.
Number of photographs: 4.
Photograph scale: 1:23,600.
Focal length: 6 in.
Date flown: Feb. 9, 1955.
Map reference: U.S. Geol. Survey Heavener 15-min quadrangle, scale 1:62,500.
Geology reference: Miser, H. D., 1954, Geologic map of Oklahoma: U.S. Geol. Survey, scale 1:500,000.

Features illustrated (set nos. Okla. 3 A–D in northeast corner of photographs).—These photographs show a folded sequence of Pennsylvanian sedimentary rocks. Narrow sandstone ridges are separated by broad lowlands underlain by shale. The locality is near Heavener, about on the boundary between the Ouachita Mountains and the Arkansas Valley. Pine Mountain syncline (south half of photograph 3 B), held up by the Hartshorne Sandstone, plunges eastward and is bordered on the south by the meandering Poteau River. To the north, sandstone ridges outline an east-plunging anticline (center of photograph 3 C). Strip mines have been opened in the rocks of Pine Mountain, and the same rocks form a narrow ridge north of the anticline (northwest quadrant of photograph 3 D).

Okla. 4. Rich Mountain syncline

County: Le Flore.
Lat 34°41′ N.; long 94°34′ W.
Number of photographs: 3.
Photograph scale: 1:23,600.
Focal length: 6 in.
Date flown: Feb. 12, 1955.
Map reference: U.S. Geol. Survey Page 15-min quadrangle, scale 1:62,500.
Geology reference: Seely, D. R., 1963, Structure and stratigraphy of the Rich Mountain area, Oklahoma and Arkansas: Oklahoma Geol. Survey Bull. 101, 173 p.; geol. map (pl. 1), scale 1:41,600.

Features illustrated (set nos. Okla. 4 A–C in northeast corner of photographs).—Thick sandstone beds separated by thin shale units (Game Refuge Formation of Mississippian age) form the Wilton Mountain, an east-plunging syncline (east half of photograph 4 B). The surrounding lowlands are underlain largely by shale (Wesley, Markham Mill, and Prairie Mountain Formations). Rich Mountain to the north (center of photograph 4 B) is held up by massive sandstone (Wildhorse

Mountain Formation) on the north limb of the syncline. Small bare masses of scree lie on the south slope of Rich Mountain. The gullied lower slopes on the north side of the mountain are mantled by bouldery colluvuim.

Oreg. 1. Dunes near Cape Lookout

County: Tillamook.
Lat 45°18′ N.; long 123°57′ W.
Number of photographs: 3.
Photograph scale: 1:37,400.
Focal length: 6 in.
Date flown: Aug. 10, 1953.
Map reference: U.S. Geol. Survey Tillamook 15-min quadrangle, scale 1:62,500.
Geology reference: Cooper, W. S., 1958, Coastal sand dunes of Oregon and Washington: Geol. Soc. America Mem. 72, p. 77–78, pls. 2 and 16.

Features illustrated (set nos. Oreg. 1 A–C in northeast corner of photographs).—An enormous parabolic-shaped dune, about 3.5 miles long, has its long axis orientated about N. 30° E.; it lies to the northwest of Sand Lake, a broad tidal flat. The seaward side of the sand ridge has been sliced away by the sea on a north-south line. Along the shore near Chamberlain Lake the truncated sand body is about 80 feet high. The main part of the dune is stabilized and densely forested; its outer margins are steep-sided ridges. A strip of bare mobile sand lies along the axis of the parabola from the shore to its northeast tip, including four units, each with an active slip face. Cape Lookout is a narrow rocky headland, bordered by 400-foot cliffs that jut out about 1½ miles into the Pacific Ocean. The Cape and adjacent highlands are composed of Miocene basalt that overlies sandstone and shale, also of Tertiary age and forms the lower hills in the east part of photograph 1 B.

Oreg. 2. Stabilized and active dunes near Siuslaw River

County: Lane.
Lat 44°01′ N.; long 124°07′ W.
Number of photographs: 3.
Photograph scale: 1:37,400.
Focal length: 6 in.
Date flown: Sept. 29, 1954.
Map reference: U.S. Geol. Survey Heceta Head and Siltcoos Lake 15-min quadrangles, scale 1:62,500.
Geology reference: Cooper, W. S., 1958, Coastal sand dunes of Oregon and Washington: Geol. Soc. America Mem. 72, p. 88–93, pls. 3, 7, 14, 15, and 17.

Features illustrated (set nos. Oreg. 2 A–C in southeast corner of photographs).—North of the river (photograph 2 B), the dune complex is more than 3 miles wide. A north-south highway follows a flat densely forested plain where sand is completely stabilized. To the east and west are areas of active sand, elongate north-south. The lakes near the north edge of the same exposure are streams ponded by dune sand. The longshore (northward) transport of suspended sediment is indicated both by turbidity patterns in the sea and by the northward shift of the mouth of Siuslaw River, a distance of about 3 miles.

Oreg. 3. Coastal dunes near Siltcoos River

County: Douglas and Lane.
Lat 43°53′ N.; long 124°09′ W.
Number of photographs: 3.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Oct. 14, 1952.
Map reference: U.S. Geol. Survey Siltcoos Lake 15-min quadrangle, scale 1:62,500.
Geology reference: Cooper, W. S., 1958, Coastal sand dunes of Oregon and Washington: Geol. Soc. America Mem. 72, p. 104–110, pls. 3, 19, and 20.

Features illustrated (set nos. Oreg. 3 A–C in southeast corner of photographs).—North of the river (north half of photograph 3 B) the dune belt, about 1¾ miles wide, is largely bare sand broken by a few small forested areas. The bare sand has a pattern of northeast-trending ridges transverse to the prevailing winds; near the east edge of the area this pattern is superposed on larger northwest-trending sand ridges. South of the river the dune belt is less than a mile wide between mountains and beach. Between beach and dunes is a strip of small hillocks, in part grassed, which Cooper calls a "marram-grass foredune."

Oreg. 4. Crater Lake

County: Klamath.
Lat 42°56′ N.; long 122°06′ W.
Number of photographs: 5.
Photograph scale: 1:54,000.
Focal length: 6 in.
Date flown: Aug. 9, 1953.
Map reference: U.S. Geol. Survey Medford sheet, scale 1:250,000.
Geology reference: Williams, Howel, 1941, Crater Lake, the story of its origin: Berkeley, California Univ. Press, 97 p.

Features illustrated (set nos. Oreg. 4 A–E in northeastern corner of photographs).—These photographs show the lake and a part of the eastern and western slopes of Mount Mazama. The U-shaped valleys on the slopes of the volcano are cut off by the walls of the crater. These valleys were carved by alpine glaciers that mantled the upper slopes of the volcano at the time of the violent eruptions that led to the disappearance of the top of Mount Mazama and the formation of Crater Lake and Wizard Island, a cinder cone.

Oreg. 5. Patterned ground south of Owyhee Reservoir

County: Malheur.
Lat 43°14′ N.; long 117°25′ W.
Number of photographs: 2.
Photograph scale: 1:27,700.
Focal length: 5.2 in.
Date flown: Sept. 14, 1946.

Map reference: U.S. Geol. Survey Boise sheet, scale 1:250,000.
Geology reference: Malde, H. E., 1964, Patterned ground in the western Snake River Plain, Idaho: Geol. Soc. America Bull., v. 75, no. 3, p. 191–208.

Features illustrated (set nos. Oreg. 5 A–B in northeast corner of photographs).—Mounds of silt surrounded by rock rubble form a distinctive spotted pattern on weathered upland basalt and rhyolite. The pattern is characteristic of extensive basaltic terranes in the Columbia Plateau and the Snake River Plain; it is presumably a periglacial landform.

Pa. 1. Nippenose Valley anticline

County: Lycoming and Clinton.
Lat 41°10′ N.; long 77°12′ W.
Number of photographs: 4.
Photograph scale: 1:60,000.
Focal length: 6 in.
Date flown: Oct. 25, 1956.
Map reference: U.S. Geol. Survey Williamsport 15-min quadrangle, scale 1:62,500.
Geology reference: Gray, Carlyle, and others, 1960, Geologic map of Pennsylvania: Pennsylvania Geol. Survey, 4th ser., scale 1:250,000.

Features illustrated (set nos. Pa. 1 A–D in southwest corner of photographs).—Ordovician limestones on the crest of a northeast-trending anticline floor Nippenose Valley (south half of photograph 1 C) where there are many sinkholes. The valley is completely surrounded by ridges of outward-dipping quartzitic sandstone of the Juniata and Tuscarora Formations. The surface drainage of the valley is by way of Antes Creek that flows northward through a gorge into the broad valley of the West Branch Susquehanna River near Jersey Shore. This valley is underlain in large part by shale of Silurian and Devonian age. On the south edge of the flood plain of the West Branch, Antes Creek has built an alluvial fan.

Pa. 2. Strip mines in anthracite coal near Mount Pleasant

County: Schuylkill.
Lat 40°42′ N.; long 76°20′ W.
Number of photographs: 3.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Aug. 29, 1958.
Map reference: U.S. Geol. Survey Minersville 7½-min quadrangle, scale 1:24,000.
Geology reference: Wood, G. H., Jr., Trexler, J. P., Yelenosky, Andy, and Soren, Julian, 1958, Geology of the northern half of the Minersville quadrangle and a part of the northern half of the Tremont quadrangle, Schuylkill County, Pennsylvania: U.S. Geol. Survey Coal Inv. Map C–43, scale 1:12,000.

Features illustrated (set nos. Pa. 2 A–C in southeast corner of photographs).—The coal beds occur in closely folded synclines; so, in general, the mines outline synclines and the wooded areas anticlines. In the central part of photograph 2 B, for example, the east-northeast-trending belt of strip mines just north of the center of the photograph is along a syncline. The adjacent anticline to the south is marked by a strip of woods that passes through the center of the photograph, and the next syncline passes under the large flat-topped heap of coal-mine debris (gray areas east of center of same exposure).

Near the west edge of the photograph the northern syncline is replaced by several minor folds whose axes rise westward. Rocks stratigraphically below the coal beds are brought to the ground surface. The traces of several thrust faults cross the photographs but are not readily apparent.

Pa. 3. Hickory Run boulder field, Pocono Plateau

County: Carbon.
Lat 41°03′ N.; long 75°39′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: June 8, 1959.
Map reference: U.S. Geol. Survey Stoddartsville 15-min quadrangle, scale 1:62,500.
Geology reference: Smith, H. T. U., 1953, The Hickory Run boulder field, Carbon County, Pennsylvania: Am. Jour. Sci., v. 251, no. 9, p. 625–642.

Features illustrated (set nos. Pa. 3 A–B in southeast corner of photographs).—The boulder field (northeast quadrant of photograph 3 A) is a bare expanse of boulders of locally derived quartzitic sandstone and conglomerate as much as 20 feet long. The field slopes about 1°. Smith believes that the boulder field was formed when the Wisconsin ice sheet was close by. The terminal moraine lies just north of the field outside the area of overlap.

Pa. 4. Ice-marginal delta near Saylorsburg

County: Monroe.
Lat 40°56′ N.; long 75°18′ W.
Number of photographs: 3.
Photograph scale: 1:23,600.
Focal length: 6 in.
Date flown: Apr. 24, 1957.
Map reference: U.S. Geol. Survey Saylorsburg 7½-min quadrangle, scale 1:24,000.

Features illustrated (set nos. Pa. 4 A–C in northeast corner of photographs).—Flat-topped grassy hill in center of photograph 4 B is a delta; borrow pit on its east edge (at west end of bedrock ridge) exposes gravel and sand. The delta was built by a melt-water stream emerging from ice that covered much of the northeast quadrant of the photograph and which dammed the northeast drainage (McMichael Creek) tributary to Delaware River. The discontinuous ridge north of the delta is probably an esker formed by the delta-building stream. Depressions, chiefly at the northeast edge of the delta, are kettles. Lacustrine silt and clay underlie lowlands east, south, and west of delta. The hills in the southwest corner of the photograph were not glaciated in Wisconsin time (J. B. Epstein, written commun., 1964).

Pa. 5. Terminal moraine at Bangor

County: Northampton and Monroe.
Lat 40°53′ N.; long 75°13′ W.
Number of photographs: 3.
Photograph scale: 1:23,600.
Focal length: 6 in.
Date flown: Apr. 24, 1951.
Map reference: U.S. Geol. Survey Stroudsburg, Saylorsburg, Wind Gap, and Bangor 7½-min quadrangles, scale 1:24,000.
Geology reference: Leverett, Frank, 1934, Glacial deposits outside the Wisconsin terminal moraine in Pennsylvania: Pennsylvania Geol. Survey, 4th ser., Bull. G 7.

Features illustrated (set nos. Pa. 5 A–C in northeast corner of photographs).—Wisconsin terminal moraine on the southeast slope of Blue Mountain near Bangor. A belt of hummocky topography with many small ponds and swamps and as much as half a mile wide extends north and south in the eastern half of photograph 5 B. In Blue Mountain (northwest quadrant of photograph 5 C), the quartzite and conglomerate of the Shawangunk Conglomerate overlie the Martinsburg Shale and form a southwestward-plunging syncline. The numerous slate quarries in the Martinsburg near Bangor are now largely inactive.

Pa. 6. Delaware Water Gap

County: Monroe and Northampton, Pa., and Warren, N.J.
Lat 40°58′ N.; long 75°07′ W.
Number of photographs: 3.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: May 6, 1959.
Map reference: U.S. Geol. Survey Stroudsburg and Portland 7½-min quadrangles, scale 1:24,000; Delaware Water Gap 15-min quadrangle, scale 1:62,500.
Geology reference: Epstein, J. B., 1966, Structural control of wind gaps and water gaps and of stream capture in the Stroudsburg area, Pennsylvania and New Jersey: *in* Geological Survey research 1966, U.S. Geol. Survey Prof. Paper 550-B, p. B80–B86.

Features illustrated (set nos. Pa. 6 A–C in southeast corner of photographs).—Delaware Water Gap is one of the classic water gaps in the Appalachian Highlands, about 1,200 feet deep and less than a mile wide at the top. The nearly flat top of Kittatinny Mountain at the gap was believed by W. M. Davis to be a remnant of his Schooley peneplain preserved on top of the resistant quartzite that can be seen dipping steeply to the northwest. The course of the river through the ridge has been variously attributed to superposition or to structural control related to joints, faults, or plunging folds.

P.R. 1. Doline or sinkhole karst topography

County: Municipio de Camuy.
Lat 18°24′ N.; long 66°51′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 6 in.
Date flown: Feb. 12, 1963.
Map reference: U.S. Geol. Survey Camuy 7½-min quadrangle, scale 1:20,000.
Geology reference: Monroe, W. H., 1963, Geology of the Camuy quadrangle, Puerto Rico: U.S. Geol. Survey Geol. Quad. Map GQ–197.

Features illustrated (set nos. P.R. 1 A–B in northeast corner of photographs).—Intricate karst topography formed in lower Miocene limestone which dips 3°–5° N. Sinkholes are as deep as 60 meters and towers as high as 40 meters. Apparently bare southern and eastern slopes in the southern part of the area are covered by a mat of ferns in contrast to the densely wooded northern and western slopes. Near the southeast corner of photograph 1 B a stream appears at the head of an alluviated valley, flows north and then east and disappears in a cave (in woods), flows underground to the north, reappears in another alluviated valley, flows through a small gorge, and finally disappears in a cave that is near the east edge of photograph 1 B.

P.R. 2. Tower karst and haystack hills

County: Municipios de Camuy and Hatillo.
Lat 18°26′ N.; long 66°49′ W.
Number of photographs: 3.
Photograph scale: 1:20,000.
Focal length: 6 in.
Date flown: Feb. 8, 1963.
Map reference: U.S. Geol. Survey Camuy 7½-min quadrangle, scale 1:20,000.
Geology reference: Monroe, W. H., 1963, Geology of the Camuy quadrangle, Puerto Rico: U.S. Geol. Survey Geol. Quad. Map GQ–197.

Features illustrated (set nos. P.R. 2 A–C in northeast corner of photographs).—Parallel valleys, apparently joint controlled, are in tower karst on both sides of the canyon of Rio Camuy. The rock is nearly horizontal, very pure compact chalk, cemented on surface to very compact dense limestone. Many mogotes or haystack hills, projecting through a mantle of alluvial clayey sand, appear in photograph 2 C.

P.R. 3. Observatory sinkhole and exhumed buried hill

County: Municipios de Arecibo and Utuado.
Lat 18°21′ N.; long 66°45′ W.
Number of photographs: 3.
Photograph scale: 1:20,000.

Focal length: 6 in.
Date flown: Mar. 21, 1963.
Map reference: U.S. Geol. Survey Bayaney and Utuado 7½-min quadrangles, scale 1:20,000.
Geology reference: Zapp, A. D., Bergquist, H. R., and Thomas, C. R., 1948, Tertiary geology of the coastal plains of Puerto Rico: U.S. Geol. Survey Oil and Gas Inv. Prelim. Map 85.

Features illustrated (set nos. P.R. 3 A–C in northeast corner of photographs).—An exceptionally large sinkhole, 400 meters in diameter and 70 meters deep, is the site of the Arecibo Ionospheric Observatory. The entrance of the underground course of Rio Tanamá is just to the south of sinkhole. Mixed doline and tower karst topography are well shown in all three photographs. Smooth topography in the southeast quadrant of photograph 3 B is an inlier of weathered volcanic rocks—an exhumed buried hill. A small tower of limestone just west of the crest is a hum, or residual karst hill.

P.R. 4. Canyon of Rio Grande de Arecibo

County: Municipio de Arecibo.
Lat 18°23′ N.; long 66°41′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 6 in.
Date flown: Feb. 22, 1963.
Map reference: U.S. Geol. Survey Arecibo and Utuado 7½-min quadrangles, scale 1:20,000.
Geology reference: Zapp, A. D., Bergquist, H. R., and Thomas, C. R., 1948, Tertiary geology of the coastal plains of Puerto Rico: U.S. Geol. Survey Oil and Gas Inv. Prelim. Map 85.

Features illustrated (set nos. P.R. 4 A–B in northeast corner of photographs).—The valley of the Rio Grande de Arecibo has an alluvial floor about 1 kilometer wide and almost vertical walls as much as 180 meters high. The surrounding uplands have a well-formed sinkhole karst topography in gently north-dipping Aguada Limestone (northern part of area) and Montebello Member of the Cibao Formation (southern part of area). In the valley near the south edge of the photographs is an area of small tower karst formed in the Lares Limestone.

P.R. 5. Eolianite ridges and sea cliffs on north coast

County: Municipio de Manati.
Lat 18°28′ N.; long 66°29′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 6 in.
Date flown: Feb. 8, 1963.
Map reference: U.S. Geol. Survey Manati and Barceloneta 7½-min quadrangles, scale 1:20,000.
Geology reference: Monroe, W. H., 1962, Geology of the Manati quadrangle, Puerto Rico: U.S. Geol. Survey Misc. Geol. Inv. Map I-334. 1960, Sinkholes and towers in the karst area of north-central Puerto Rico, *in* Short papers in the geological sciences: U.S. Geol. Survey Prof. Paper 400-B, p. B356–B360.

Features illustrated (set nos. P.R. 5 A–B in northeast corner of photographs).—A ridge of eolianite (calcareous dune sand cemented by action of underground water) forms Punta Marchiquita (center of photograph 5 B). To the west of the area behind (south of) the eolianite ridge are sand flats alternating with marshes; just west of Punta Marchiquita is a small reverberation bay whose beach has the form of the wave front of the refracted waves that enter the narrow mouth of the bay. To the south, a higher ridge of eolianite forms a sea cliff, in part now abandoned. Inland, ridges made up of haystack hills (mogotes) rise above a plain mantled by alluvial sand.

P.R. 6. Joint-controlled solution trenches (zanjones)

County: Municipios de Morovis and Ciales.
Lat 18°22′ N.; long 66°27′ W.
Number of photographs: 3.
Photograph scale: 1:20,000.
Focal length: 6 in.
Date flown: Jan. 16, 1964.
Map reference: U.S. Geol. Survey Ciales 7½-min quadrangle, scale 1:20,000.
Geology reference: Monroe, W. H., 1964, The zanjón, a solution feature of karst topography in Puerto Rico, *in* Geological Survey research 1964: U.S. Geol. Survey Prof. Paper 501-B, p. B126–B129; see fig. 4.

Features illustrated (set nos. P.R. 6 A–C in northeast corner of photographs).—The southeast quadrant of photograph 6 B shows compound or multiple zanjones—enlarged solution joints that form parallel valleys in thin-bedded limestone. In the southwest quadrant of the same exposure there is a lateral facies change to massive limestone and well-formed tower karst. In the north half of the same exposure the massive limestone is overlain by calcareous clay. A steep south-facing escarpment at the extreme north edge of the same photograph is a cuesta capped by a thick bed of hard limestone.

P.R. 7. Tower karst

County: Municipios de Vega Baja and Manati.
Lat 18°24′ N.; long 66°26′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 6 in.
Date flown: Feb. 12, 1963.
Map reference: U.S. Geol. Survey Manati 7½-min quadrangle, scale 1:20,000.
Geology reference: Monroe, W. H., 1962, Geology of the Manati quadrangle, Puerto Rico: U.S. Geol. Survey Misc. Geol. Inv. Map I-334. Monroe, W. H., 1960, Sinkholes and towers in the karst area of north-central Puerto Rico, *in* Short papers in the geological sciences: U.S. Geol. Survey Prof. Paper 400-B, p. B356–B360.

Features illustrated (set nos. P.R. 7 A–B in northeast corner of photographs).—Mogotes or haystack hills surrounded by alluvial "blanket" sand. Many mogotes are steeper on their west-facing slopes than on their east-facing slopes; shelter caves and cliffs are common on the west-facing slopes but rare on other slopes.

P.R. 8. Landslides near Corozal

County: Municipios de Corozal and Vega Alta.
Lat 18°21′ N.; long 66°21′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 6 in.
Date flown: Jan. 16, 1964.
Map reference: U.S. Geol. Survey Corozal 7½-min quadrangle, scale 1:20,000.
Geology reference: Monroe, W. H., 1964, Large retrogressive landslides in northern Puerto Rico, *in* Geological Survey research 1964: U.S. Geol. Survey Prof. Paper 501-B, p. B123–B125.

Features illustrated (set nos. P.R. 8 A–B in northeast corner of photographs).—The triangular-shaped lowland, largely in the northwest quadrant of photograph 8 A, is bounded on the north and southwest by limestone cliffs. To the south and southeast are low hills of volcanic and intrusive rocks. The lowland is covered by landslide debris whose surface is irregular and hummocky in contrast to the fine-scale dissection of the igneous rocks to the south and the tower karst on the limestone to the east and west. As the Río Cibuco, that skirts the north edge of the lowland, cut down through the limestone, blocks of the limestone broke off the adjacent cliffs and slid on the clay that underlies the massive beds. By these processes the lowland has been widened and mantled by bouldery deposits.

R.I. 1. Charlestown ablation moraine

County: Washington.
Lat 41°24′ N.; long 71°36′ W.
Number of photographs: 4.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Nov. 12, 1951.
Map reference: U.S. Geol. Survey Kingston and Carolina 7½-min quadrangles, scale 1:24,000.
Geology reference: Kaye, C. A., 1960, Surficial geology of the Kingston quadrangle, Rhode Island: U.S. Geol. Survey Bull. 1071–I, p. 341–396.

Features illustrated (set nos. R.I. 1 A–D in southeast corner of photographs).—A segment of the Charlestown moraine (north half of photograph 1 B) and its outwash plain (south half of same photograph). The ridges on the moraine represent superglacial debris that slid into crevasses in the wasting ice; the mound-shaped hills are similar fillings of large depressions in the ice. The material is till and some sand and gravel. The ridges fronting the moraine on the north and south are colluvial ramparts. Stratified sand and gravel form the outwash plain that slopes gently southward from the moraine and is drowned at its southern edge where ponds are formed by building of beaches between headlands.

S.C. 1. Cottonpatch Bay

County: Horry.
Lat 33°47′ N.; long 78°57′ W.
Number of photographs: 3.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Feb. 23, 1958.
Map reference: U.S. Geol. Survey Nixonville and Myrtle Beach 15-min quadrangles, scale 1:62,500.
Geology reference: Prouty, W. F., 1952, Carolina Bays and their origin: Geol. Soc. America Bull., v. 63, p. 167–224.

Features illustrated (set nos. S.C. 1 A–C in southeast corner of photographs).—Cottonpatch Bay (north half of photograph 1 B), an elliptical-shaped swamp about three-quarters of a mile in diameter, is surrounded by a nearly continuous low sandy ridge. The Carolina "bays" are particularly abundant on the Carolina coastal plain and have been the subject of controversy since they first became readily discernible with the advent of aerial photography.

These bays transect many narrow closely spaced parallel sandy ridges and swamps, apparently ancient shore features.

S. Dak. 1. Cuestas near Hot Springs on southeast flank of Black Hills

County: Fall River and Custer.
Lat 43°27′ N.; long 103°25′ W.
Number of photographs: 5.
Photograph scale: 1:68,800.
Focal length: 6 in.
Date flown: Aug. 25, 1953.
Map reference: U.S. Geol. Survey Hot Springs, Minnekahta NE., and Buffalo Gap 7½-min quadrangles, scale 1:24,000.
Geology reference: Darton, N. H., 1902, Description of the Oelrichs quadrangle [South Dakota]: U.S. Geol. Survey Geol. Atlas, Folio 85. (Out of print.)

Features illustrated (set nos. S. Dak. 1 A–E in northeast corner of photographs).—Carboniferous, Jurassic, and Cretaceous sedimentary rocks dip southeast off the Black Hills uplift. Carboniferous limestone forms hills just west of Hot Springs (southwest quadrant of photograph 1 D). The city is in a shale lowland (Spearfish) bounded to the east by hills of Jurassic and Cretaceous rocks, capped by Dakota Sandstone (southwest and northeast quadrants of photograph 1 C). The Dakota forms a conspicuous dip slope on west side of broad shale valley (southeast quadrant of same photograph) that contains a low but prominent limestone cuesta. Gravel terraces border the meandering Cheyenne River (southeast quadrant of photograph 1 B).

S. Dak. 2. Sheep Mountain Table, Badlands National Monument

County: Shannon and Pennington.
Lat 43°41′ N.; long 102°34′ W.
Number of photographs: 3.
Photograph scale: 1:17,000.
Focal length: 6 in.
Date flown: Oct. 13, 1948.
Map reference: U.S. Geol. Survey Sheep Mountain Table 7½-min quadrangle, scale 1:24,000.
Geology reference: Smith, K. G., 1958, Erosional processes and land forms in Badlands National Monument, South Dakota: Geol. Soc. America Bull., v. 69, no. 8, p. 975–1008.

Features illustrated (set nos. S. Dak. 2 A–C in northeast corner of photographs).—This flat mesa is surrounded by badlands carved in essentially flat-lying beds of clay, lenticular sandstone, conglomerate, and volcanic ash of Oligocene age. The edge of the mesa is frayed by many small gullies that have a dendritic pattern. The floors of the badland washes on either side of the mesa are 300–400 feet below the mesa top.

S. Dak. 3. Clastic dikes in badlands at head of Conata Basin

County: Pennington.
Lat 43°51′ N.; long 102°15′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Sept. 21, 1938.
Map reference: U.S. Geol. Survey Quinn Table SE. and Wall SW. 7½-min quadrangles, scale 1:24,000.
Geology reference: Smith, K. G., 1958, Erosional processes and landforms in Badlands National Monument, South Dakota: Geol. Soc. America Bull., v. 69, no. 8, p. 975–1008.

Features illustrated (set nos. S. Dak. 3 A–B in southeast corner of photographs).—Flat-lying beds of clay, lenticular sandstone, conglomerate, and volcanic ash are eroded into badlands. Those in the north half of photograph 3 B form a divide—the Wall—between washes draining southward to White River and those that empty into the Cheyenne River to the northwest. The plain south of the Wall has a sod cover, and at its upper end is about 200 feet below the headwaters of the tributaries of the Cheyenne River. Sandstone dikes are conspicuous in the Oligocene sedimentary rocks of the Wall.

Tenn. 1. Sequence of abandoned meanders near Reelfoot Lake

County: Lake and Obion (Tenn.), Fulton (Ky.), and New Madrid (Mo.).
Lat 36°27′ N.; long 89°22′ W.
Number of photographs: 3.
Photograph scale: 1:60,000.
Focal length: 6 in.
Date flown: Oct. 23, 1952.
Map reference: U.S. Geol. Survey Tiptonville and Samburg 7½-min quadrangles, scale 1:24,000.
Geology reference: Fisk, H. N., 1944, Geological investigations of the alluvial valley of the lower Mississippi River: Vicksburg, Miss., Mississippi River Comm., 78 p.; see pl. 22, sheet 2, scale 1:62,500.

Features illustrated (set nos. Tenn. 1 A–C in southeast corner of photographs).—The conspicuous meandering channel in the east half of photograph 1 B contains a 2-mile-long pond (Fisk's stage 5). The low curving ridges (scrolls) on either side of the conspicuous channel (south half of the same photograph) are slightly older channels (Fisk's stages 1–4). The scrolls adjacent and nearly parallel to the Mississippi River are younger than the channel (Fisk's stages 12–16 and 19). The channel (stage 5) makes an almost complete oval. In the north half of photograph 1 C it curves west and southwest, and in the north half of photograph 1 A it enters the photograph just east of the center of the north edge; it makes a 180° turn near the center of the photograph and leaves just west of the center of the north edge. The east-west-trending scrolls within the oval are traces of the oldest channels shown (Fisk's stages E–J).

Reelfoot Lake in the south half of photograph 1 A (not in stereo) was formed about 1813 during the New Madrid earthquake.

Tenn. 2. Avalanche chutes on Mount Le Conte, Great Smoky Mountains

County: Sevier and Swain.
Lat 35°39′ N.; long 83°26′ W.
Number of photographs: 3.
Photograph scale: 1:28,000.
Focal length: 6 in.
Date flown: Mar. 30, 1963.
Map reference: U.S. Geol. Survey Great Smoky Mountains National Park, Tennessee and North Carolina (east half), scale 1:62,500.
Geology reference: Hadley, J. B., and Goldsmith, Richard, 1963, Geology of the eastern Great Smoky Mountains, North Carolina and Tennessee: U.S. Geol. Survey Prof. Paper 349–B, 118 p.; geol. map (pl. 1), scale 1:62,500.

Features illustrated (set nos. Tenn. 2 A–C in northeast corner of photographs).—The higher parts of the mountains consist of steep-sided ridges (slopes 20° or more) with narrow crests that range in altitude from about 5,500 to 6,500 feet. Forests cover the entire area except for a few heath balds on higher crests. The first-order hollows or ravines are closely spaced; the drainage density is high. The average annual rainfall is probably more than 60 inches. Avalanche scars on the south slope of Mount Le Conte (narrow white bands in north-central part of photograph 2 B) were formed during a summer thunderstorm in 1951. In the area of the avalanches the bedrock is largely slate and phyllite; elsewhere the rock is chiefly metamorphosed sandstone with interbedded slate, phyllite, and schist. All the rocks are variously folded, faulted, and metamorphosed.

The strike of the foliation commonly trends in a northeasterly direction.

Tex. 1. Strongly folded Paleozoic rocks of the Marathon Basin

County: Brewster.
Lat 30°08' N.; long 103°08' W.
Number of photographs: 3.
Photograph scale: 1:63,360.
Focal length: 5.2 in.
Date flown: May 15, 1954.
Map reference: U.S. Geol. Survey Marathon 15-min quadrangle, scale 1:62,500.
Geology reference: King, P. B., 1937, Geology of the Marathon region, Texas: U.S. Geol. Survey Prof. Paper 187, 148 p.; geol. map (pl. 24), scale 1:62,500.

Features illustrated (set nos. Tex. 1 A–C in southwest corner of photographs).—A part of the Marathon Basin, an area of low country where the surrounding Cretaceous rocks have been stripped off to expose strongly folded Paleozoic rocks. The prominent narrow zigzag ridges are composed of novaculite and of limestone; the lowlands are underlain by sandstone, shale, and limestone. The Paleozoic rocks form close folds. The folds trend northeast and are overturned to the northwest. The folds are broken by thrust faults and locally by many cross faults. The regional structure is beautifully shown on these photographs that are at approximately the same scale as King's geologic map.

Tex. 2. Sierra Diablo, a tilted and faulted plateau

County: Hudspeth and Culberson.
Lat. 31°17' N.; long. 104°54' W.
Number of photographs: 3.
Photograph scale: 1:43,150.
Focal length: 5.2 in.
Date flown: Feb. 13, 1948.
Map reference: U.S. Geol. Survey Van Horn sheet, scale 1:250,000.
Geology reference: King, P. B., 1965, Geology of Sierra Diablo region, Texas: U.S. Geol. Survey Prof. Paper 480, 185 p.; geol. map (pl. 1), scale 1:62,500.

Features illustrated (set nos. Tex. 2 A–C in southeast corner of photographs).—The Sierra Diablo or Diablo Plateau lies on the west side of Salt Basin, a prominent down-faulted block in the Sacramento section of the Basin and Range province. These photographs show a part of the southern end of the plateau about 15 miles north of Van Horn. Drainage on the plateau is westward from the more than 1,000-foot escarpment that overlooks Salt Basin. Carboniferous or Permian limestone unconformably overlies Precambrian sandstone. The limestone dips very gently northeastward and is cut by northwest-trending normal faults. Both fault and bedding planes can be seen in these photographs.

Tex. 3. Sinkholes on the southern High Plains

County: Ector and Crane.
Lat. 31°40' N.; long. 102°25' W.
Number of photographs: 2.
Photograph scale: 1:63,360.
Focal length: 5.2 in.
Date flown: May 3, 1954.
Map reference: U.S. Geol. Survey Pecos sheet, scale 1:250,000.
Geology reference: Hoots, H. W., 1926, Geology of a part of western Texas and southeastern New Mexico, with special reference to salt and potash: U.S. Geol. Survey Bull. 780, p. 33–126; geol. map, (pl. 10), scale 1:1,000,000.

Features illustrated (set nos. Tex. 3 A–B in southwest corner of photographs).—The slightly dissected eastern edge of the southern High Plains or Llano Estacado is dotted with shallow sinkholes. The plains are mantled by upper Cenozoic alluvial and eolian deposits cemented near the surface by caliche (includes the Ogallala and younger formations). The underlying indurated bedrock is limestone and sandstone of Cretaceous age. These rocks are largely concealed. The rock benches on the sides of shallow valleys in the southeast quadrant of photograph 3 A are sandstone.

Tex. 4. High Plains escarpment east of Lubbock

County: Crosby.
Lat 33°35' N.; long 101°13' W.
Number of photographs: 2.
Photograph scale: 1:63,360.
Focal length: 5.2 in.
Date flown: Jan. 23, 1954.
Map reference: U.S. Geol. Survey Lubbock sheet, scale 1:250,000.
Geology reference: Frye, J. C., and Leonard, A. B., 1957, Studies of Cenozoic geology along the eastern margin of the Texas High Plains, Armstrong to Howard Counties: Texas Univ. Bur. Econ. Geology Rept. Inv. 32, 62 p.

Features illustrated (set nos. Tex. 4 A–B in northeast corner of photographs).—Escarpment on the west side of White River (east half of photograph 4 A), a tributary of Brazos River. Massive beds of sand cemented by caliche cap the plains and in many places rest directly on sand and gravel (Ogallala Formation of Pliocene age). Triassic sedimentary rocks crop out near White River. Badlands east of the escarpment have a high drainage density compared with the virtually undissected plains to the west where numerous large shallow depressions are as much as half a mile in diameter.

Tex. 5. Dissected plateaus carved in flat-lying well-bedded limestone

County: Val Verde.
Lat 29°56' N.; long 101°12' W.
Number of photographs: 2.
Photograph scale: 1:46,000.
Focal length: 6 in.
Date flown: Apr. 24, 1950.
Map reference: U.S. Geol. Survey Bakers Crossing 15-min quadrangle, scale 1:62,500.
Geology reference: Freeman, V. L., 1965, Geologic map of the

Bakers Crossing quadrangle, Val Verde County, Texas: U.S. Geol. Survey Misc. Geol. Inv. Map I-434, scale 1:62,500.

Features illustrated (set nos. Tex. 5 A–B in northeast corner of photographs).—In the southern part of the Edwards Plateau, flat-lying Upper Cretaceous limestones show finely banded outcrop patterns. The small gray-toned plateau tops in the southwest quadrant of photograph 5 A are capped by a thin-bedded flaggy limestones (Boquillas Flags). Surrounding these flats are lighter toned gentle slopes that extend down to a conspicuous light band. These slopes are bare outcrops of thin- to thick-bedded limestone (Buda Limestone). The lower and steeper slopes, down to floors of narrow valleys tributary to Devils River (northeast quadrant of photograph 5 A), are underlain by thin- to thick-bedded gray limestone (Georgetown Limestone). Total relief is about 300 feet.

Tex. 6. Paleozoic and Cretaceous rocks along the Pedernales River

County: Gillespie and Blanco.
Lat 30°14′ N.; long 98°36′ W.
Number of photographs: 4.
Photograph scale: 1:19,000.
Focal length: 6 in.
Date flown: Mar. 8, 1958.
Map reference: U.S. Geol. Survey Cave Creek School, Rocky Creek, Stonewall, and Hye 7½-min quadrangles, scale 1:24,000.
Geology references: Barnes, V. E. [1952], Geologic map of the Gold quadrangle, Gillespie County, Texas: Texas Univ. Bur. Econ. Geology Geol. Quad. Map [No. 9], scale 1:31,680. [1952], Geologic map of the Stonewall quadrangle, Gillespie and Kendall Counties, Texas: Texas Univ. Bur. Econ. Geology Geol. Quad. Map [No. 14], scale 1:31,680. [1952], Geologic map of the North Grape Creek quadrangle, Blanco and Gillespie Counties, Texas: Texas Univ. Bur. Econ. Geology Geol. Quad. Map [No. 10], scale 1:31,680.

Features illustrated (set nos. Tex. 6 A–D in northeast corner of photographs).—The Pedernales River separates Cretaceous limestones of the Edwards Plateau to the south from Precambrian and Paleozoic rocks of the Central Mineral district to the north. Near the north edge of photograph 6 D, granite crops out on the crest of a west-trending anticline. Steeply dipping beds of sandstone and limestone (Cambrian) on the south limb of the anticline cross the northeast-flowing Pedernales River. Further upriver and in the beds of small tributary streams, flat-lying beds of limestone and dolomite are visible in many places. The adjacent lowlands have a thin covering of virtually flat-lying Lower Cretaceous sand, silt, and clay, including beds of limestone in the upper part. The Paleozoic rocks commonly form wooded hills and project above the adjacent lowlands of Cretaceous rocks.

Utah 1. Open pit at Bingham

County: Salt Lake.
Lat 40°32′ N.; long 112°08′ W.
Number of photographs: 3.
Photograph scale: 1:37,400.
Focal length: 6 in.
Date flown: June 20, 1950.
Map reference: U.S. Geol. Survey Bingham Canyon and Lark 7½-min quadrangles, scale 1:24,000.
Geology reference: Hunt, R. N., 1933, Bingham mining district: Internat. Geol. Cong., 16th, Washington, 1933, Guidebook 17, Excursion 2, p. 45–56.

Features illustrated (set nos. Utah 1 A–C in southeast corner of photographs).—This great open pit is nearly 1,500 feet deep and 2 miles in diameter. The ore is disseminated pyrite and lesser amounts of copper sulfides in monzonite, quartzite, and limestone.

Utah 2. Faulted moraines at mouth of Little Cottonwood Canyon

County: Salt Lake.
Lat 40°34′ N.; long 111°48′ W.
Number of photographs: 3.
Photograph scale: 1:28,000.
Focal length: 6 in.
Date flown: Aug. 2, 1962.
Map reference: U.S. Geol. Survey Draper 7½-min quadrangle, scale 1:24,000.
Geology reference: Richmond, G. M., 1964, Glaciation of Little Cottonwood and Bells Canyons, Wasatch Mountains, Utah: U.S. Geol. Survey Prof. Paper 454-D, p. D1–D41; geol. map (pl. 1), scale 1:24,000.

Features illustrated (set nos. Utah 2 A–C in southeast corner of photographs).—Moraines of Bull Lake Glaciation form ridges on the south side of the mouth of Little Cottonwood Canyon (larger canyon in northeast quadrant of photograph 2 B) and on either side of the next canyon to the south—Bells Canyon—where the ridge fills the canyon's mouth and encloses a small reservoir. The inner part of Bells Canyon morainic loop is believed by Richmond to belong to the younger Pinedale glaciation. Fault scarps cut the Bull Lake moraines north and south of Bells Canyon reservoir. These moraines merge westward with gravelly deltaic deposits of Pleistocene Lake Bonneville that underlie a westward-sloping plain. South of Bells Canyon are prominent fault scarps and triangular facets on the mountain front.

Utah 3. Glaciation of Little Cottonwood Canyon, Wasatch Mountains

County: Salt Lake.
Lat 40°33′ N.; long 111°42′ W.
Number of photographs: 3.
Photograph scale: 1:37,400.
Focal length: 6 in.
Date flown: June 30, 1950.
Map reference: U.S. Geol. Survey Dromedary Peak 7½-min quadrangle, scale 1:24,000.
Geology reference: Richmond, G. M., 1964, Glaciation of Little Cottonwood and Bells Canyons, Wasatch Mountains,

Utah: U.S. Geol. Survey Prof. Paper 454–D, D1–D41; geol. map (pl. 1), scale 1:24,000.

Features illustrated (set nos. Utah 3 A–C in southeast corner of photographs).—The north side of this west-draining canyon has short and steep-sided tributary valleys in contrast to the prominent cirques at the heads of long glacial troughs that drain northward to the main canyon. Small loop moraines of the Pinedale Glaciation cross Little Cottonwood Creek south of the center of the north edge of photograph 3 B. The cirques contain rock glaciers, extensive talus mantles, and small lakes. Arêtes and horns are conspicuous.

Utah 4. Landslides on Thousand Lake Mountain

County: Wayne.
Lat 38°25′ N.; long 111°30′ W.
Number of photographs: 4.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Aug. 17, 1952.
Map reference: U.S. Geol. Survey Torrey and Loa 15-min quadrangles, scale 1:62,500.
Geology reference: Smith, J. F., Huff, L. C., Hinrichs, E. N., and Luedke, R. G., 1963, Geology of the Capitol Reef area, Wayne and Garfield Counties, Utah: U.S. Geol. Survey Prof. Paper 363, 102 p.; geol. map (pl. 1), scale 1:62,500.

Features illustrated (set nos. Utah 4 A–D in southeast corner of photographs).—The mountain is composed of Cretaceous shale and sandstone capped by lava flows. Its upper slopes are mantled by landslide debris. The elongate ridges west of the scarp surrounding the flat treeless summit (photograph 4 D) are tilted, and in places jumbled blocks of lava have slid only short distances. Farther down the slope to the west (southwest quadrant of photograph 4 A), younger landslide deposits have long ridges that parallel the direction of movement of the material downslope between projecting hills of bedrock.

Utah 5. Landslide on north slope of Boulder Mountain

County: Wayne.
Lat 38°16′ N.; long 111°29′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Oct. 29, 1950.
Map reference: U.S. Geol. Survey Torrey and Grover 15-min quadrangles, scale 1:62,500.
Geology reference: Flint, R. F., and Denny, C. S., 1958, Quaternary geology of Boulder Mountain, Aquarius Plateau, Utah: U.S. Geol. Survey Bull. 1061–D, p. 103–164; geol. map (pl. 6), scale 1:63,360. See fig. 29. Smith, J. F., Jr., Huff, L. C., Hinrichs, E. N., and Luedke, R. G., 1963, Geology of the Capitol Reef area, Wayne and Garfield Counties, Utah: U.S. Geol. Survey Prof. Paper 363, 102 p.; geol. map (pl. 1), scale 1:62,500.

Features illustrated (set nos. Utah 5 A–B in southeast corner of photographs).—Lower part of a complex landslide (west half of photograph 5 B) on the north slope of Boulder Mountain. The terminal part of the slide (northwest quadrant of same photograph) is a lobate earthflow that fills an older valley and has well-defined margins. The toe is convex downstream. Upstream and parallel to it are several arcuate ridges. The central part of the slide (southwest quadrant of photograph 5 B) consists of boulders and finer debris arranged in discontinuous irregular ridges parallel with the margin of the slide. This landslide is the Coleman slide of Flint and Denny. The mountain summit and upper slopes are shown in Utah 6.

Utah 6. Drift lobe and rock glaciers on Boulder Mountain

County: Wayne.
Lat 38°13′ N.; long 111°29′ W.
Number of photographs: 3.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Oct. 29, 1950.
Map reference: U.S. Geol. Survey Grover 15-min quadrangle, scale 1:62,500.
Geology reference: Flint, R. F., and Denny, C. S., 1958, Quaternary geology of Boulder Mountain, Aquarius Plateau, Utah: U.S. Geol. Survey Bull. 1061–D, p. 103–164, fig. 25; geol. map, scale 1:63,360. Smith, J. F., Jr., Huff, L. C., Hinrichs, E. N., and Luedke, R. G., 1963, Geology of the Capitol Reef area, Wayne and Garfield Counties, Utah: U.S. Geol. Survey Prof. Paper 363, 102 p., fig. 19; geol. map, scale 1:62,500.

Features illustrated (set nos. Utah 6 A–C in southeast corner of photographs).—An icecap on the flat top of Boulder Mountain (south part of photograph 6 C) spilled northward over the summit cliff and flowed northeast for a distance of about 3 miles from the cliff (northeast corner of photograph 6 B). The surface of the drift deposited by this ice lobe is irregular and hummocky, with many undrained depressions, some of which contain lakes. At a later time, rock glaciers formed along the base of the cliff. These bulbous masses of bouldery material show concentric ridges, particularly near the terminal margins. Boulder Mountain, a part of the Aquarius Plateau, is underlain by almost flat-lying Tertiary volcanic rocks. The plateau top is at an altitude of about 11,000 feet.

Utah 7. Fracture patterns in Navajo Sandstone of Capitol Reef

County: Wayne.
Lat 38°18′ N.; long 111°14′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Oct. 29, 1950.
Map reference: U.S. Geol. Survey Fruita 15-min quadrangle, scale 1:62,500.
Geology reference: Smith, J. F., Jr., Huff, L. C., Hinrichs, E. N., and Luedke, R. G., 1963, Geology of the Capitol Reef area, Wayne and Garfield Counties, Utah: U.S. Geol. Survey Prof. Paper 363, 102 p.; geol. map, scale 1:62,500.

Features illustrated (set nos. Utah 7 A–B in southeast corner of photographs).—North-trending fractures in thick beds of Navajo Sandstone forming crest of Capitol Reef control a conspicuous pattern of gullies and ravines which have almost vertical walls as much as several hundred feet high. The beds dip very gently to the east and are overlain (in northeast quadrant photograph 7 A) by a sequence of even-bedded siltstone, claystone, sandstone, and gypsum (Carmel Formation) that lack conspicuous joints. Some of the southeast-trending lineaments are along faults. The village of Fruita (southwest corner of photograph 7 A) is at the point where Fremont River enters the Reef. A high gravel terrace lies just to the west of the village.

Utah 8. Capitol Reef, a monocline, near Pleasant Creek

County: Wayne.
Lat 38°12′ N.; long 111°11′ W.
Number of photographs: 2.
Photograph scale: 1:31,680.
Focal length: 6 in.
Date flown: July 17, 1938.
Map reference: U.S. Geol. Survey Notom 15-min quadrangle, scale 1:62,500.
Geology reference: Hunt, C. B., Averitt, Paul, and Miller, R. L., 1953, Geology and geography of the Henry Mountains region, Utah: U.S. Geol. Survey Prof. Paper 228, 234 p., fig. 94; geol. map, scale 1:125,000. Smith, J. F., Jr., Huff, L. C., Hinrichs, E. N., and Luedke, R. G., 1963, Geology of the Capitol Reef area, Wayne and Garfield Counties, Utah: U.S. Geol. Survey Prof. Paper 363, 102 p.; geol. map, scale 1:62,500.

Features illustrated (set nos. Utah 8 A–B in southeast corner of photographs).—Capitol Reef is the boundary between the High Plateaus of Utah and the Canyon Lands sections of the Colorado Plateaus province. Eastward-dipping Triassic and Jurassic sedimentary rocks form an impressive monocline more than 1,000 feet high, locally known as a reef. The prominent cliff west of the center of the photographs is the Wingate Sandstone; west of it are Triassic shale, siltstone, sandstone, and limestone that near the west edge of the photographs underlie a dip slope. The ledge above the Wingate cliff is the Kayenta Formation.

The white sandstone knobs and domes (east half of photographs) are the Navajo Sandstone. Some of the domes resemble in form the dome of the Capitol in Washington, D.C., from which feature the reef takes its name. Conspicuous joints parallel the strike of the Navajo Sandstone and can be seen to pass under the overlying and unjointed Carmel Formation.

Utah 9. Badlands near South Caineville mesa

County: Wayne.
Lat 38°18′ N.; long 110°57′ W.
Number of photographs: 2.
Photograph scale: 1:31,680.
Date flown: July 12, 1939.
Map reference: U.S. Geol. Survey Factory Butte 15-min quadrangle, scale 1:62,500.
Geology reference: Hunt, C. B., Averitt, Paul, and Miller, R. L., 1953, Geology and geography of the Henry Mountains region, Utah: U.S. Geol. Survey Prof. Paper 228, 234 p., fig. 99; geol. map, scale 1:125,000.

Features illustrated (set nos. Utah 9 A–B in northeast corner of photographs).—The mesa is capped by the Emery Sandstone Member of the Mancos Shale; the badlands surrounding it are underlain by the Blue Gate Shale Member of the Mancos. Pediments have been formed between the foot of the badlands and the alluvium along Sweetwater Creek (southeast quadrant of photograph 9 B).

Utah 10. Gravel benches on the west side of Mount Ellen

County: Wayne and Garfield.
Lat 38°09′ N.; long 110°53′ W.
Number of photographs: 3.
Photograph scale: 1:60,000.
Focal length: 6 in.
Date flown: Oct. 13, 1955.
Map reference: U.S. Geol. Survey Salina sheet, scale 1:250,000.
Geology reference: Hunt, C. B., Averitt, Paul, and Miller, R. L., 1953, Geology and geography of the Henry Mountains region, Utah: U.S. Geol. Survey Prof. Paper 228, p. 192, pls. 18 and 19, figs. 103 and 104.

Features illustrated (set nos. Utah 10 A–C in southeast corner of photographs).—Hunt has mapped gravel deposits of five different ages on the piedmont west of the Henry Mountains. In the northeast corner of photograph 10 C is circular Table Mountain, a diorite porphyry bysmalith, and the boulder-covered summit ridge of Mount Ellen is in the southeast quadrant of the same photograph. (See Hunt's pl. 18.) The Cedar Creek Benches are near the center of photograph 10 C, and those along Dugout Creek are in the southwest quadrant of the same photograph. Several recently completed or imminent stream diversions are shown. The place where Birch Creek is in imminent danger of being diverted, shown in Utah 11, is in the southeast corner of photograph 10 A.

Utah 11. Imminent stream diversion on north side of Mount Ellen

County: Wayne and Garfield.
Lat 38°13′ N.; long 110°46′ W.
Number of photographs: 3.
Photograph scale: 1:40,000.
Focal length: 6 in.
Date flown: Sept. 6, 1961.
Map reference: U.S. Geol. Survey Salina sheet, 1:250,000.
Geology reference: Hunt, C. B., Averitt, Paul, and Miller, R. L., 1953, Geology and geography of the Henry Mountains region, Utah: U.S. Geol. Survey Prof. Paper 228, p. 192–195, pls. 18 and 20, figs. 103A and 105.

Features illustrated (set nos. Utah 11 A–C in southeast corner of photographs).—Where streams emerge from the Henry Mountains onto the surrounding piedmont, they have steeper gradients and coarser grained bedloads than their tributaries that rise on the piedmont and are cutting largely in shale and thin-bedded sandstone. Stream piracies have occurred and others are imminent. In the central part of the north half of photograph 11 A are the Birch Creek Benches. (See Hunt's pl. 18.) The benches are underlain by gravel deposited by Birch Creek that rises on the north slope of Mount Ellen (southwest quadrant of photograph 11 A) and now flows along the west edge of the benches on the east rim of the headwaters of a deep valley (Jet Basin, northwest quadrant of same photograph). The head (south end) of this valley is north of and several hundred feet lower than Birch Creek where it leaves the mountains. Diversion of Birch Creek northwestward into Jet Basin at a point near the mountain front will require only the breaching of a narrow divide that is 20 feet high.

Utah 12. Sand dunes in Green River Desert

County: Emery.
Lat 38°32′ N.; long 110°35′ W.
Number of photographs: 3.
Photograph scale: 1:31,680.
Focal length: 6 in.
Date flown: Oct. 20, 1938.
Map reference: U.S. Geol. Survey Temple Mountain 15-min quadrangle, scale 1:62,500.
Geology reference: Hunt, C. B., Averitt, Paul, and Miller, R. L., 1953, Geology and geography of the Henry Mountains region, Utah: U.S. Geol. Survey Prof. Paper 228, p. 175–177, fig. 93.

Features illustrated (set nos. Utah 12 A–C in southeast corner of photographs).—Individual sand hills are barchans, concave in plan to leeward (northeast). The barchans are clustered in crescentic arcs that are concave to windward (southwest). Nearly straight ridges of sand extend southwestward from the tips of each crescentic arc. The sand can be seen to bury an area of badlands to west of the north-south road. The bedrock is flat-lying Entrada Sandstone. Gibson Butte in the northwest corner of photograph 12 B is an outlier of the overlying sandstone of the Curtis Formation.

Utah 13. Upheaval Dome

County: San Juan.
Lat 38°26′ N.; long 109°56′ W.
Number of photographs: 4.
Photograph scale: 1:20,000.
Focal length: 6 in.
Date flown: Sept. 21, 1951.
Map reference: U.S. Geol. Survey Upheaval Dome 15-min quadrangle, scale 1:62,500.
Geology reference: McKnight, E. T., 1940, Geology of area between Green and Colorado Rivers, Grand and San Juan Counties, Utah: U.S. Geol. Survey Bull. 908, 147 p.; geol. map, pl. 1, scale 1:62,500.

Features illustrated (set nos. Utah 13 A–D in southeast corner of photographs).—This symmetrical structure is clearly shown on these excellent photographs. The dome is expressed topographically as a circular lowland, about a mile in diameter, surrounded by a high rim breached at one point by Upheaval Canyon. Shale, mudstone, and sandstone form small irregular hills in the center of the dome surrounded by a lowland (Moenkopi and Chinle Formations). The rim includes an inner and an outer ring of massive sandstone separated by more shaly and thin-bedded rocks (Wingate Sandstone, Kayenta Sandstone, and Navajo Sandstone). Steer Mesa and Holeman Spring are on the south side of Upheaval Dome.

Utah 14. Cliffs and domes in Navajo Sandstone, Zion National Park

County: Washington and Kane.
Lat 37°13′ N.; long 112°55′ W.
Number of photographs: 3.
Photograph scale: 1:63,360.
Focal length: 6 in.
Date flown: June 16, 1953.
Map reference: U.S. Geol. Survey Zion National Park, Zion Canyon Section, scale 1:31,680.
Geology reference: Gregory, H. E., 1950, Geology and geography of the Zion Park region, Utah and Arizona: U.S. Geol. Survey Prof. Paper 220, 200 p.; geol. map (pl. 2), scale 1:125,000.

Features illustrated (set nos. Utah 14 A–C in southeast corner of photographs).—Flat-lying massive Jurassic sandstones enclose Zion Canyon (northwest quadrant of photograph 14 B) and Parunuweap Canyon (south edge of same photograph). Both these narrow canyons are floored with Chinle Shale. The Navajo Sandstone forms the canyon rim and shows conspicuous north-south jointing. The smoother upland away from the canyons is underlain by shales of the Carmel Formation. The Great White Throne, a monolith of Navajo Sandstone, stands just south of the horseshoe bend (Big Bend) in Zion Canyon (northwest quadrant of photgraph 14 B). Some of the smaller streams that flow in Navajo Sandstone have meanders that appear to be joint controlled, for example, the stream just southwest of the center of photograph 14 B and in the upper part of Parunuweap Canyon (in southeast quadrant).

Utah 15. Glen Canyon Colorado River below Hite

County: Garfield and San Juan.
Lat 37°46′ N.; long 110°28′ W.
Number of photographs: 3.
Photograph scale: 1:31,680.

Focal length: 6 in.
Date flown: July 23, 1938.
Map reference: U.S. Geol. Survey Hite 15-min quadrangle, scale 1:62,500.
Geology reference: Hunt, C. B., Averitt, Paul, and Miller, R. E., 1953, Geology and geography of the Henry Mountains region, Utah: U.S. Geol. Survey Prof. Paper 228, 234 p., fig. 87; geol. map, scale 1:125,000.

Features illustrated (set nos. Utah 15 A–C in south corner of photographs).—A U-shaped bend of the river, The Horn (east quadrant of photograph 15 B), is about 6 miles downstream from Hite (north corner of photograph). In the center of the southwest edge of the photograph there is a mesa capped by dark shale of the Carmel Formation (Jurassic). The mesa is about 2,000 feet above the river. The white knobby Navajo Sandstone, below the Carmel, shows conspicuous north-south joints. The still older Kayenta Formation makes smooth slopes and ledges above prominent cliffs of Wingate Sandstone; three benches of Wingate Sandstone between The Horn and Hite show joints in as many different directions. A lower bench just above the river is held up by the Shinarump Conglomerate of Triassic age. Sand bars are in the river at mouths of tributaries.

Vt. 1. Topographic grain related to structural complexity and glacial scour

County: Rutland.
Lat 43°45′ N.; long 73°09′ W.
Number of photographs: 3.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Aug. 27, 1942.
Map reference: U.S. Geol. Survey Bomoseen, Proctor, Brandon, and Sudbury 7½-min quadrangles, scale 1:24,000.
Geology reference: Zen, E-an, 1961, Stratigraphy and structure at the north end of the Taconic Range in west-central Vermont: Geol. Soc. America Bull., v. 72, no. 2, p. 293–338; geol. map (pl. 1), scale 1:48,000.

Features illustrated (set nos. Vt. 1 A–C in southeast corner of photographs).—A series of east-west ridges or cuestas wind across these photographs and display a conspicuous north-south topographic grain. These features are related to the interaction of three factors: (1) a tendency for the planar or linear structures in these complexly folded lower Paleozoic rocks to dip or plunge to the south or southeast; (2) a second period of folding along a north-south axis which gives the east-west trending formations their sinuosity; and (3) glacial scour by southward-moving ice. The northernmost cuesta—just south of High Pond (northwest quadrant of photograph 1 B)—is held up by resistant arkose and graywacke; a second—Ganson Hill (west of center of same exposure)—by compact cherty slate; a less conspicuous one—just north of curving road (south half of same exposure)—by arkose and graywacke; and a fourth—Sargent Hill (south of curving road)—by quartzite. The open valley followed by the curving round is underlain by weak, chloritoid-bearing slate and phyllite.

Va. 1. Beech Grove cutoff, a hanging entrenched meander

County: Lee.
Lat 36°37′ N.; long 83°16′ W.
Number of photographs: 3.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Mar. 19, 1953.
Map reference: U.S. Geol. Survey Back Valley and Rose Hill 7½-min quadrangles, scale 1:24,000.
Geology reference: Miller, R. L., and Brosgé, W. P., 1954, Geology and oil resources of the Jonesville district, Lee County, Virginia: U.S. Geol. Survey Bull. 990, p. 144–150; geol. map, scale 1:24,000.

Features illustrated (set nos. Va. 1 A–C in southeast corner of photographs).—The entrenched meanders of Powell River are bordered by slip-off slopes and lie in a belt parallel to the strike of generally southward-dipping Ordovician limestones. The floor of an abandoned cut-off meander (northeast quadrant of photograph 1 A that encircles Beech Grove School hangs about 30 feet above the river. The meanders are in the noncherty Hurricane Bridge Limestone where outcrops are abundant, and the area is largely woodland. North of the river, the fields are largely in the cherty Martin Creek Limestone that is rarely seen in outcrop. Wallen Ridge (southeast corner of photograph 1 B) has a cap of Clinch Sandstone overlying shale and siltstone that form a steep gullied slope.

Va. 2. Debris avalanches formed during cloudburst

County: Augusta.
Lat 38°25′ N.; long 79°13′ W.
Number of photographs: 2.
Photograph scale: 1:10,000.
Focal length: 8.25 in.
Date flown: Mar. 13, 1955.
Map reference: U.S. Geol. Survey Parnassus 15-min quadrangle, scale 1:62,500.
Geology reference: Hack, J. T., and Goodlett, J. C., 1960, Geomorphology and forest ecology of a mountain region in the central Appalachians: U.S. Geol. Survey Prof. Paper 347, 66 p.; map, scale 1:31,680. See pl. 4.

Features illustrated (set nos. Va. 2 A–B in east corner of photographs).—A violent cloudburst in June 1949, with more than 9 inches of rain in a few hours, caused many small debris avalanches that swept away the forest cover. The accompanying floods enlarged most channelways and in places removed the forest from the entire valley floor and left bare ground. The area is one of steep-sided narrow valleys where the total relief is more than 1,500 feet. Bedrock is gently dipping Devonian and Mississippian sandstone and shale.

Va. 3. Residual manganese deposits in a synclinal valley

County: Augusta.
Lat 37°56′ N.; long 79°07′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Nov. 10, 1951.
Map reference: U.S. Geol. Survey Vesuvius 15-min quadrangle, scale 1:62,500.
Geology reference: Knechtel, M. M., 1943, Manganese deposits of the Lyndhurst-Vesuvius district, Augusta and Rockbridge Counties, Virginia: U.S. Geol. Survey Bull. 940–F, p. 190–194, pl. 29.

Features illustrated (set nos. Va. 3 A–B in southeast corner of photographs).—The west-southwest-flowing St. Mary's River near the center of photograph 3 B follows a deep synclinal trough at the top of the Antietam Quartzite of Early Cambrian age. Beds of quartzite can be seen to have steeper dips on the south limb of the syncline than on the north limb. The Tomstown (Shady) Dolomite of Cambrian age overlies the quartzite along the axis of the trough just south of the river. Because the dolomite itself is mostly weathered, only clayey residuum remains. Manganese oxides have been concentrated in the residuum. Two mine workings can be seen at east and west sides of the photographs.

Va. 4. Imminent stream capture near Mount Solon

County: Augusta.
Lat 38°22′ N.; long 79°06′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Nov. 10, 1951.
Map reference: U.S. Geol. Survey Parnassus 15-min quadrangle, scale 1:62,500.
Geology reference: Hack, J. T., 1960, Interpretation of erosional topography in humid temperate regions: Am. Jour. Sci., v. 258–A, p. 91–92. 1965, Geomorphology of the Shenandoah Valley, Virginia, and West Virginia, and origin of the residual ore deposits: U.S. Geol. Survey Prof. Paper 484, 84 p.

Features illustrated (set nos. Va. 4 A–B in southeast corner of photographs).—North River (northwest quadrant of photograph 4 A) has a broad flood plain underlain by sandstone cobbles and gravel that came from the mountains to the west (outside of area shown in photographs). Mossy Creek which drains northeast past Mount Solon (town surrounding the pond in northeast quadrant of photograph 4 A) flows on and heads in limestone bedrock and its gradient is less than North River. Near Mount Solon, the valley of Mossy Creek lies about 60 feet below that of North River. During a flood in 1949, North River spilled through the gap northwest of Mount Solon and flowed down into Mossy Creek. A permanent diversion into such a course can be predicted in the near geologic future.

Va. 5. Entrenched meanders of the North Fork Shenandoah River

County: Shenandoah.
Lat 38°54′ N.; long 78°28′ W.
Number of photographs: 3.
Photograph scale: 1:27,200.
Focal length: 5.2 in.
Date flown: Mar. 9, 1945.
Map reference: U.S. Geol. Survey Strasburg and Edinburg 15-min quadrangles, scale 1:62,500.
Geology reference: Hack, J. T., and Young, R. S., 1959, Entrenched meanders of the North Fork of the Shenandoah River, Virginia: U.S. Geol. Survey Prof. Paper 354–A, 10 p.

Features illustrated (set nos. Va. 5 A–C in northeast corner of photographs).—These meanders near Woodstock are incised 100–150 feet below the adjoining shale uplands. The sinuosity (distance along stream divided by distance down valley) attains the high value of 3.2. The meander belt is 1–2½ miles wide and is localized within the outcrop area of the Martinsburg Shale. The two parallel ridges in the southeast quadrant of photograph 5 B, which are of quartzite, form a syncline whose axis follows the valley between the ridges. Hack and Young believe that the meanders are caused by strong planar and prismatic structures in the Martinsburg Shale that favor northwest-southeast differential erosion.

Va. 6. Deposition and erosion at Jamestown Island

County: James City.
Lat 37°13′ N.; long 76°47′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Dec. 3, 1953.
Map reference: U.S. Geol. Survey Surry 7½-min quadrangle, scale 1:24,000.
Geology reference: Cotter, J. L., 1958, Archeological excavations at Jamestown, Colonial National Historical Park and Jamestown National Historic Site, Virginia: U.S. Natl. Park Service, Archaeol. Research Ser. 4, 299 p.

Features illustrated (set nos. Va. 6 A–B in southeast corner of photographs).—The site of the first permanent English settlement in North America (1607) is near the docks south of the center of photograph 6 B. A bridge connects the site with the mainland (northeast quadrant of photograph 6 B). The site is on a platform of wooded sandy ridges separated by tidal marsh and is adjacent to a deep channel of the tidal James River. The sandy ridges were deposited by the river on its east side, perhaps during a late-glacial high stand of the sea. When the first settlement was built, Jamestown Island was part of the mainland, and Powhatan Creek that flows southwestward from northeast corner of photograph 6 B did not reach James River. The creek turned eastward to flow past the townsite and off the photographs to the east, via what is now Back River (the stream crossed by the bridge that joins island to mainland). Erosion of the east bank of the James River, west of the bridge, during the last 300 years has cut off the townsite from the mainland.

Va. 7. Dismal Swamp and Suffolk Scarp

County: Norfolk, Nansemond, Gates, and Camden.
Lat 36°35′ N.; long 76°30′ W.
Number of photographs: 3.
Photograph scale: 1:60,000.
Focal length: 6 in.
Date flown: Dec. 8, 1959.
Map reference: U.S. Geol. Survey Lake Drummond and Suffolk 15-min quadrangles, scale 1:62,500.
Geology reference: Oaks, R. Q., Jr., and Coch, N. K., 1963, Pleistocene sea levels, southeastern Virginia: Science, v. 140, p. 979–983.

Features illustrated (set nos. Va. 7 A–C in southwest corner of photographs).—Lake Drummond is surrounded by Dismal Swamp that is underlain by 5–10 feet of fresh-water peat of Recent age. The peat rests on a complex of older Pleistocene sediments of fluvial, eolian, and marine origin. The east-facing Suffolk Scarp (west half of photograph 7 B), 10–30 feet high, was fashioned by the sea in the early Pleistocene and has been considerably dissected since that time.

Wash. 1. Mount Olympus and its glaciers

County: Jefferson.
Lat 47°48′ N.; long 123°42′ W.
Number of photographs: 5.
Photograph scale: 1:37,400.
Focal length: 6 in.
Date flown: Oct. 3, 1952.
Map reference: U.S. Geol. Survey Mount Olympus and Mount Tom 15-min quadrangles, scale 1:62,500.
Geology reference: Danner, W. R., 1955, Geology of Olympic National Park: Seattle, Washington Univ. Press, 68 p. Allen, C. R., Kamb, W. B., Meire, M. F., and Sharp, R. P., 1960, Structure of the lower Blue glacier, Washington: Jour. Geology, v. 68, no. 6, p. 601–625.

Features illustrated (set nos. Wash. 1 A–E in northeast corner of photographs).—Mount Olympus (near center of photograph 1 C) and adjacent peaks support alpine glaciers; the longest are on the north side of the peaks. Blue Glacier, one of the most thoroughly investigated glaciers in the conterminous United States, heads on the northeast slope of Mount Olympus and follows a northward-curving path. Medial morainic bands, crevasses, ice falls, and the approximate firn limit on Blue Glacier can be seen in these photographs taken in early October. Young nonforested moraines and older forest-covered morainal ridges are conspicuous down valley from some of the glaciers.

Wash. 2. Alpine glaciers on Glacier Peak

County: Snohomish.
Lat 48°07′ N.; long 121°07′ W.
Number of photographs: 3.
Photograph scale: 1:27,700.
Focal length: 5.2 in.
Date flown: Oct. 7, 1944.
Map reference: U.S. Geol. Survey Glacier Peak 15-min quadrangle, scale 1:62,500.

Features illustrated (set nos. Wash. 2 A–C in northeast corner of photographs).—This Pleistocene to Recent andesitic volcano (altitude 10,541 ft) rises about 6,000 feet above the tops of the adjacent mountains. Glaciers largely conceal the upper slopes of the peak except on its southwest side. The individual glaciers are separated by small arêtes and flow in shallow U-shaped valleys. The glacial dissection of the volcano, although only moderate, is noticeably more advanced than on Mount St. Helens. (See Wash. 7.) Adjacent photographs from this same flight strip, showing the east slope of Glacier Peak, constitute Wash. 3. (A. B. Ford, written commun., 1964).

Wash. 3. Mudflows and glacial features on east side of Glacier Peak

County: Snohomish.
Lat 48°07′ N.; long 121°02′ W.
Number of photographs: 3.
Photograph scale: 1:27,700.
Focal length: 5.2 in.
Date flown: Oct. 7, 1964.
Map reference: U.S. Geol. Survey Glacier Peak 15-min quadrangle, scale 1:62,500.

Features illustrated (set nos. Wash. 3 A–C in northeast corner of photographs).—Along the east base of Glacier Peak, Suiattle River (northeast quadrant of photograph 3 B) follows an earlier U-shaped glacial valley that has truncated spurs and hanging tributaries and that was partly buried by a large volcanic debris fan. The toe of this fan follows the west bank of the river. The fan heads on the east slope of the volcano near the tree line (northwest quadrant of same photograph). The fan is now dissected to depths of 500–1,000 feet by Suiattle River and its tributaries. Immense exposures of the material in the debris fan along the creek on south side of the fan near its apex (Chocolate Creek, northwest quadrant of photograph 3 B) suggest the presence of easterly dipping beds, more or less parallel to the fan surface. Adjacent photographs from this same flight strip, showing the summit of Glacier Peak, constitute Wash. 2 (A. B. Ford, written commun., 1964).

Wash. 4. Soil mounds on Mima Prairie

County: Thurston.
Lat 46°53′ N.; long 123°03′ W.
Number of photographs: 2.
Photograph scale: 1:37,400.
Focal length: 6 in.
Date flown: July 23, 1951.

Map reference: U.S. Geol. Survey Rochester 15-min quadrangle, scale 1:62,500.

Geology reference: Ritchie, A. M., 1953, The erosional origin of the Mima Mounds of southwest Washington: Jour. Geology, v. 61, no. 1, p. 41–50; see pl. 3B.

Features illustrated (set nos. Wash. 4 A–B in southeast corner of photographs).—This nearly level plain about 3 miles long and 2 miles wide is one of several prairies covered by conspicuous soil mounds or Mima Mounds. The mounds range from 10 to 70 feet in diameter and from a few inches to 7 feet high. They are rounded or oval in plan, in cross section commonly resemble a segment of a circle, and are composed of pebbly sand and silt. Ritchie attributes them to the erosion of partially thawed ice-wedge polygons.

Wash. 5. Channeled scabland: Cataract in Moses Coulee

County: Douglass and Grant.
Lat 47°30′ N.; long 119°45′ W.
Number of photographs: 4.
Photograph scale: 1:73,800.
Focal length: 6 in.
Date flown: Sept. 22, 1952.
Map reference: U.S. Geol. Survey Ritzville sheet, scale 1:250,000.
Geology reference: Bretz, J H., 1959, Washington's channeled scabland: Washington Div. Mines and Geology Bull. no. 45, 57 p.

Features illustrated (set nos. Wash. 5 A–D in southeast corner of photographs).—This great compound cataract (west of center of photograph 5 C) includes three recessional gorges that reach back upstream into a broad scabland tract. The cataract to the east started as a double cataract whose members united to leave an island in the gorge below the dry falls. Bretz believes that all three gorges and their cataracts were contemporaneous. To the north the main coulee is a gorge nearly 400 feet deep (northeast quadrant of photograph 5 B).

Wash. 6. Sand dunes near Moses Lake

County: Grant.
Lat 47°04′ N.; long 119°22′ W.
Number of photographs: 3.
Photograph scale: 1:20,000.
Focal length: 6 in.
Date flown: Aug. 11, 1954.
Map reference: U.S. Geol. Survey Moses Lake 15-min quadrangle, scale 1:62,500.

Features illustrated (set nos. Wash. 6 A–C in southeast corner of photographs).—Part of dune field damming Moses Lake. The dunes include both transverse and longitudinal forms. The sand is largely bare and is moving eastward up a low scarp and across a broad terrace. In the southern part of the area the depressions between dunes are flooded.

Wash. 7. Debris flows on Mount St. Helens, a Recent volcano

County: Skamania.
Lat 46°12′ N.; long 122°11′ W.
Number of photographs: 3.
Photograph scale: 1:47,200.
Focal length: 6 in.
Date flown: July 28, 1952.
Map reference: U.S. Geol. Survey Mount St. Helens and Spirit Lake 15-min quadrangles, scale 1:62,500.
Geology reference: Verhoogen, Jean, 1937, Mount St. Helens; a Recent Cascade volcano: California Univ., Dept. Geol. Sci. Bull., v. 24, p. 263–302. Mullineaux, D. R., and Crandell, D. R., 1962, Recent lahars from Mount St. Helens, Washington: Geol. Soc. America Bull., v. 73, p. 855–870.

Features illustrated (set nos. Wash. 7 A–C in southeast corner of photographs).—This symmetric volcano rises about 6,000 feet above the surrounding hills on the west flank of the Cascade Range. The present cone may have been built during the last thousand years, and the small glaciers on its steep slopes have not yet cut deep broad valleys. The areas of sparse vegetation on the lower slopes of the volcano have been devastated by debris flows or lahars within the past century.

Wash. 8. Channeled scabland: Giant current ripple marks

County: Adams.
Lat 47°03′ N.; long 118°04′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Aug. 28, 1950.
Map reference: U.S. Geol. Survey Ritzville sheet, scale 1:250,000.
Geology reference: Bretz, J H., Smith, H. T. U., and Neef, G. E., 1956, Channeled scabland of Washington: New data and interpretations: Geol. Soc. America Bull., v. 67, p. 1030 and pl. 16, fig. 2.

Features illustrated (set nos. Wash. 8 A–B in southeast corner of photographs).—A scabland channel with small rock basins in basalt between two small smooth cultivated loess-covered hills (north half of photograph 8 A). In the south half of the same exposure are what Bretz describes as current ripples that have a wavelength of perhaps 200 feet.

Wash. 9. Channeled scabland: Staircase Rapids bar

County: Adams.
Lat 46°47′ N.; long 118°17′ N.
Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Aug. 29, 1950.
Map reference: U.S. Geol. Survey Washtucna 15-min quadrangle, scale 1:62,500.
Geology reference: Bretz, J H., 1959, Washington's channeled scabland: Washington Div. Mines and Geology Bull. 45, 57 p., fig. 27.

Features illustrated (set nos. Wash. 9 A–B in southeast corner of photographs).—On the terrace near the center of photograph 9 B are east-west-trending parallel ridges and swales spaced 175–350 feet apart. Bretz believes that these ridges are giant current ripple marks on a bar built by a south-flowing river, a part of his "Spokane flood." To the east and west are loess-covered "Palouse" hills.

Wash. 10. Channeled scabland: Palouse River canyon

County: Adams, Franklin, and Whitman.
Lat 46°43′ N.; long 118°14′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Aug. 28, 1950.
Map reference: U.S. Geol. Survey Starbuck, Benge, Washtucna, and Haas 15-min quadrangles, scale 1:62,500.
Geology reference: Bretz, J H., Smith, H. T. U., and Neff, G. E., 1956, Channeled scabland of Washington: New data and interpretations: Geol. Soc. America Bull., v. 67, p. 1015–1020.

Features illustrated (set nos. Wash. 10 A–B in southeast corner of photographs).—Palouse River in the north half of photograph 10 B flows westward in a broad open valley—Washtucna Coulee—but near the west edge of the photograph it makes a sharp bend and flows south in a narrow canyon toward the Snake River. Bretz believes that Washtucna Coulee follows the preglacial course of Palouse River. Glacial floodwaters overtopped the bedrock divide south of the Coulee (the area shown in photograph 10 A) and at least 350 feet above the preglacial Palouse Valley. The divide area is now scabland in which the Palouse River has carved a 400-foot deep canyon. The paper cited above includes references to other interpretations of these features.

Wash. 11. Channeled scabland: Giant ripple marks along Union Flat Creek

County: Whitman.
Lat 46°50′ N.; long 117°56′ W.
Number of photographs: 2.
Photograph scale: 1:20,000.
Focal length: 8.25 in.
Date flown: Sept. 21, 1950.
Map reference: U.S. Geol. Survey La Crosse 15-min quadrangle, scale 1:62,500.
Geology reference: Bretz, J H., 1959, Washington's channeled scabland: Washington Div. Mines and Geology Bull., no. 45, 57 p.

Features illustrated (set nos. Wash. 11 A–B in southeast corner of photographs).—Giant ripple marks on terraces along Union Flat Creek near its junction with Palouse River (northwest corner of photograph 11 B). Scabland on basalt forms the surrounding uplands.

W. Va. 1. Strip mines in the Appalachian Plateaus

County: Mingo and Pike.
Lat 37°39′ N.; long 82°11′ W.
Number of photographs: 3.
Photograph scale: 1:31,000.
Focal length: 6 in.
Date flown: Mar. 16, 1957.
Map reference: U.S. Geol. Survey Matewan 7½-min quadrangle, scale 1:24,000.
Geology reference: Stose, G. W., and Ljungstedt, O. A., 1932, Geologic map of West Virginia: West Virginia Geol. Survey, scale 1:500,000.

Features illustrated (set nos. W. Va. 1 A–C in southeast corner of photographs).—This area of steep-sided wooded hills with a maximum relief of about 1,200 feet is underlain by virtually flat-lying coal-bearing shale and sandstone of Pennsylvanian age. The region borders on Tug Fork, which flows in a narrow meandering valley and forms the Kentucky-West Virginia boundary. Some of the coal beds have been extensively worked; strip mines contour the slopes of hills near Tug Fork.

W. Va. 2. Chestnut Ridge anticline near Coopers Rock

County: Monongalia.
Lat 39°38′ N.; long 79°49′ W.
Number of photographs: 3.
Photograph scale: 1:31,000.
Focal length: 6 in.
Date flown: Apr. 12, 1956.
Map reference: U.S. Geol. Survey Lake Lynn and Masontown 7½-min quadrangles, scale 1:24,000.
Geology reference: Hare, C. E., 1957, Geology of Coopers Rock State Forest and Mont Chateau State Park: West Virginia Geol. and Econ. Survey, State Park Series Bull. 5, 26 p.

Features illustrated (set nos. W. Va. 2 A–C in southeast corner of photograph).—Cheat River cuts through Chestnut Ridge in a 1,200-foot-deep gorge that runs northwest diagonally across photograph 2 B. In part of its course the river is known as Lake Lynn, being dammed a few miles downstream (just north of northwest corner of photograph 2 A). Chestnut Ridge is an anticline. In the walls of the gorge the resistant sandstone beds (Pottsville Series) that make the ridge can be seen to rise southeastward. The lower cultivated land to the northwest is on younger beds of shale, sandstone, limestone, and coal (Conemaugh Series).

W. Va. 3. Potomac River gorge near Harpers Ferry

County: Jefferson, Loudoun, Washington, and Frederick.
Lat 39°19′ N.; long 77°43′ W.
Number of photographs: 4.
Photograph scale: 1:24,000.
Focal length: 6 in.
Date flown: Mar. 28, 1965.
Map reference: U.S. Geol. Survey Charles Town and Harpers Ferry 7½-min quadrangles, scale 1:24,000.
Geology reference: Nickelsen, R. P., 1956, Geology of the Blue Ridge near Harpers Ferry, West Virginia: Geol. Soc. America Bull., v. 67, p. 239–270; geol. map (pl. 1), scale 1:25,000.

Features illustrated (set nos. W. Va. 3 A–D in northeast corner of photographs).—The Shenandoah River joins the Potomac River at Harpers Ferry to flow eastward through the mountains by way of two water gaps, each about 900 feet deep. Rapids can be seen where resistant strata crop out on the river's bed. Blue Ridge (south of the junction of two rivers) and Short Ridge (southwest quadrant of photograph 3 D) are Weverton Quartzite (Cambrian); they form recumbent folds overturned to the northwest. Some of the individual quartzite beds can be seen in cliffs along the river. Meta-igneous and metasedimentary rocks of Precambrian age underlie the lowlands between the two quartzite mountains.

Wis. 1. Drumlins and moraines of Green Bay glacier near Fond du Lac

County: Fond du Lac.
Lat 43°50′ N.; long 88°20′ W.
Number of photographs: 4.
Photograph scale: 1:23,600.
Focal length: 6 in.
Date flown: Apr. 24, 1952.
Map reference: U.S. Geol. Survey Fond du Lac 15-min quadrangle, scale 1:62,500.
Geology reference: Alden, W. C., 1918, The Quaternary geology of southeastern Wisconsin: U.S. Geol. Survey Prof. Paper 106, p. 250–256, pls. 3 and 28.

Features illustrated (set nos. Wis. 1 A–D in northeast corner of photographs).—Roughly the north half of photograph 1 B is moraine of Green Bay glacier and the south half is a drumlin field. The drumlins are small, almost circular, and commonly less than half a mile long. Some of the larger drumlins trend southwest and have small south-trending knolls on their crests. The material is a compact calcareous clayey till. The stones in the drift are about 91 percent local limestone and 9 percent Precambrian crystalline rocks.

Wis. 2. The great Kettle Moraine near Campbellsport

County: Fond du Lac and Sheboygan.
Lat 43°36′ N.; long 88°11′ W.
Number of photographs: 4.
Photograph scale: 1:23,600.
Focal length: 6 in.
Date flown: Apr. 30, 1952.
Map reference: U.S. Geol. Survey Kewaskum 15-min quadrangle, scale 1:62,500.
Geology reference: Alden, W. C., 1918, The Quaternary geology of southeastern Wisconsin: U.S. Geol. Survey Prof. Paper 106, 356 p.; geol. map (pl. 3), scale 1:250,000.

Features illustrated (set nos. Wis. 2 A–D in northeast corner of photographs).—These photographs show a 7-mile strip across the Kettle Moraine. East of the moraine lies a kettled outwash plain (east half of photograph 2 A). To the west is a 2-mile-wide belt of rough kettle moraine (west half of same exposure). East Branch Milwaukee River meanders on the floor of a broad north-south trench (center of photograph 2 C) that to the north is floored with outwash and to the south with swamp deposits. The moraine extends westward from the trench for several miles (photograph 2 D) and includes some narrow ridges that may be ice-channel fillings.

Wis. 3. The great Kettle Moraine east of Whitewater

County: Jefferson and Walworth.
Lat 42°50′ N.; long 88°37′ W.
Number of photographs: 4.
Photograph scale: 1:17,000.
Focal length: 6 in.
Date flown: Apr. 8, 1955.
Map reference: U.S. Geol. Survey Whitewater 15-min quadrangle, scale 1:62,500.
Geology reference: Alden, W. C., 1918, The Quaternary geology of southeastern Wisconsin: U.S. Geol. Survey Prof. Paper 106, 356 p.; geol. map (pl. 3), scale 1:250,000.

Features illustrated (set nos. Wis. 3 A–D in northeast corner of photographs).—This massive interlobate moraine was formed between the Lake Michigan lobe and the Green Bay lobe of the Wisconsin ice sheet. The gently rolling poorly drained drift plain of the Green Bay lobe (photograph 3 A) is bordered on the east by a belt of small wooded hills 50–150 feet high that mark the west edge of the Kettle Moraine (east edge of photograph 3 B). The moraine has a gently undulating surface pitted by iceblock holes 50–80 feet deep (east half of photograph 3 C). Much of the surface of the moraine is only slightly above that of the drift plain to the west. Most of the material in the moraine is probably gravel, sand, and clay, especially in its eastern part (photograph 3 D).

Wyo. 1. Beartooth fault and landslide lake

County: Park.
Lat 44°54′ N.; long 109°20′ W.
Number of photographs: 4.
Photograph scale: 1:37,400.
Focal length: 6 in.
Date flown: July 7, 1948.
Map reference: U.S. Geol. Survey Deep Lake 15-min quadrangle, scale 1:62,500.

Features illustrated (set nos. Wyo. 1 A–D in northeast corner of photographs).—Deep Lake (photograph 1 B), in a canyon carved in Precambrian granite gneiss at the south end of the Beartooth Mountains, is dammed by a landslide that is younger than the glacier that built the conspicuous moraines at the canyon's mouth (east edge of photograph 1 C). The landslide debris that moved down the north wall of the canyon left a reentrant at the top of the slope.

The Beartooth fault, a high-angle reverse fault, forms the east front of the mountains (east half of photograph 1 C). Precambrian rocks to the west are in contact with upturned and broken Paleozoic sedimentary rocks to the east. Another landslide mantles the mountain front just south of the moraines (W. G. Pierce, written commun., 1964).

Wyo. 2. Cody terrace, Shoshone River

County: Park.
Lat 44°31′ N.; long 109°03′ W.
Number of photographs: 2.
Photograph scale: 1:37,400.
Focal length: 6 in.
Date flown: July 7, 1948.
Map reference: U.S. Geol. Survey Cody 15-min quadrangle, scale 1:62,500.
Geology reference: Mackin, J. H., 1937, Erosional history of the Big Horn Basin, Wyoming: Geol. Soc. America Bull., v. 48, no. 6, p. 813–893. Moss, J. H., and Bonini, W. E., 1961, Seismic evidence supporting a new interpretation of the Cody Terrace near Cody, Wyoming: Geol. Soc. America Bull., v. 72, p. 547–556. Pierce, W. G., and Andrews, D. A., 1941, Geology and oil and coal resources of the region south of Cody, Park County, Wyoming: U.S. Geol. Survey Bull. 921–B, p. 99–180; geol. map (pl. 11), scale 1:63,360.

Features illustrated (set nos. Wyo. 2 A–B in northeast corner of photographs).—Cody is on a gravel terrace or flight of steps ranging from 120 to 190 feet above the river (Cody terrace); another broad plain lies about 80 feet above the Cody level (Powell terrace). Mackin holds that these are rock-cut terraces, whereas Moss and Bonini postulate an alluvial origin. The hogbacks south of the terraces are thin sandstone beds separated by thick shale units on the northeast limb of an anticline whose axis trends northwestward across the southwest quadrant of photograph 2 B. The prominent hogback that ends at the center of the west side of photograph 2 A is sandstone of the Cloverly Formation of Cretaceous age. The Permian and Triassic Chugwater Formation is exposed in the center of the anticline.

Wyo. 3. Piracy of Greybull River near Burlington

County: Big Horn.
Lat 44°27′ N.; long 108°27′ W.
Number of photographs: 2.
Photograph scale: 1:57,900.
Focal length: 6 in.
Date flown: Aug. 23, 1954.
Map reference: U.S. Geol. Survey YU Bench NE. and Burlington 7½-min quadrangles, scale 1:24,000.
Geology reference: Mackin, J. H., 1936, The capture of the Greybull River: Am. Jour. Sci., 5th ser., v. 31, p. 373–385. Robinove, C. J., and Langford, R. H., 1963, Geology and ground-water resources of the Greybull River-Dry Creek area, Wyoming: U.S. Geol. Survey Water-Supply Paper 1596, 88 p.; see pl. 1 and figs. 6 and 7.

Features illustrated (set nos. Wyo. 3 A–B in northeast corner of photographs).—The flood plain of the Greybull River (south half of photograph 3 B) slopes eastward on the south side of Table Mountain (east-central part of same photograph). The broad mesa (Emblem Bench) that slopes gently northeast through the center of photograph 3 A is the remnant of an ancient flood plain of Greybull River that lay on the north side of Table Mountain. While the river flowed north of the mountain, a small stream worked headward (west) in soft rocks at a lower elevation south of the mountain. Greybull River abandoned its gravel-covered flood plain to the north—Emblem Bench—and was diverted southward into the lower channel south of the mountain. A part of the bench and of the Greybull River flood plain are shown at a larger scale in Wyo. 4.

Wyo. 4. Emblem Bench and Greybull River flood plain

County: Big Horn.
Lat 44°28′ N.; long 108°29′ W.
Number of photographs: 3.
Photograph scale: 1:23,600.
Focal length: 6 in.
Date flown: Aug. 6, 1948.
Map reference: U.S. Geol. Survey YU Bench NE. and Burlington 7½-min quadrangles, scale 1:24,000.
Geology reference: Mackin, J. H., 1936, The capture of the Greybull River: Am. Jour. Sci., 5th ser., v. 31, p. 373–385. Robinove, C. J., and Langford, R. H., 1963, Geology and ground-water resources of the Greybull River-Dry Creek area, Wyoming: U.S. Geol. Survey Water-Supply Paper 1596, 88 p.; see pl. 1.

Features illustrated (set nos. Wyo. 4 A–C in northeast corner of photographs).—This gravel-covered bench between Dry Creek and the flood plain of Greybull River includes at least two levels; its eastern part is irrigated. The surface of the bench, which marks an abandoned course of Greybull River, is smooth compared with the surface of the younger terraces. The flood plain of the river shows abandoned channels and meander scars. These photographs show in more detail a part of the area that is included in Wyo. 3.

Wyo. 5. Devils Tower and Belle Fourche River

County: Crook.
Lat 44°35′ N.; long 104°43′ W.
Number of photographs: 2.
Photograph scale: 1:28,400.
Focal length: 6 in.
Date flown: Sept. 15, 1953.
Map reference: U.S. Geol. Survey Devils Tower and Oshoto 15-min quadrangles, scale 1:62,500.
Geology reference: Robinson, C. S., 1956, Geology of Devils Tower National Monument, Wyoming: U.S. Geol. Survey Bull. 1021–I, p. 289–302; geol. map (pl. 30), scale 1:4,800.

Features illustrated (set nos. Wyo. 5 A–B in northeast corner of photographs).—Devils Tower is a steep-sided shaft of igneous rock that has vertical columnar jointing and that rises about 700 feet above the surrounding hills. At the base of the Tower is an apron of talus and landslide material that rests on flat-lying beds of sandstone, shale, and gypsum of Jurassic age. The Belle Fourche River meanders across a half-mile-wide flood plain. The flood plain itself also has a meandering course and is incised about 200 feet below the adjacent hilltops.

Wyo. 6. Circle Ridge Dome

County: Fremont.
Lat 43°32′ N.; long 109°04′ W.
Number of photographs: 3.
Photograph scale: 1:23,600.
Focal length: 6 in.
Date flown: Oct. 22, 1948.
Map reference: U.S. Geol. Survey Thermopolis sheet, scale 1:250,000.
Geology reference: Andrews, D. A., 1944, Geologic and structure contour map of the Maverick Springs area, Fremont County, Wyoming: U.S. Geol. Survey Oil and Gas Inv. Prelim. Map 13.

Features illustrated (set nos. Wyo. 6 A–C in southeast corner of photographs).—This asymmetrical dome (photograph 6 B), which has nearly vertical beds on its southwest flank and gentler dips on its northeast side, has a central lowland underlain by Triassic shale and sandstone (Chugwater Formation) surrounded by outward-dipping sandstone ridges separated by shale units, largely of Jurassic age (Morrison and Sundance Formations). The beds of the northwest-plunging terminus of the dome are faulted. Most of the streams draining the dome follow strike valleys around the central lowland and flow outward across the resistant beds only near the south end of the anticline.

Wyo. 7. Little Dome

County: Fremont.
Lat 43°25′ N.; long 108°52′ W.
Number of photographs: 2.
Photograph scale: 1:23,600.
Focal length: 6 in.
Date flown: Oct. 20, 1948.
Map reference: U.S. Geol. Survey Thermopolis sheet, scale 1:250,000.
Geology reference: Andrews, D. A., 1944, Geologic and structure contour map of the Maverick Springs area, Fremont County, Wyoming: U.S. Geol. Survey Oil and Gas Inv. Prelim. Map 13.

Features illustrated (set nos. Wyo. 7 A–B in southeast corner of photographs).—A small area of Jurassic rocks is exposed in the center of this elongate dome that is largely outward-dipping Cretaceous beds composed of shale and some sandstone. The beds are tightly folded along the southeast-plunging anticlinal axis. The lowlands around the dome are underlain by Cody Shale that is largely concealed by alluvium and terrace deposits.

Wyo. 8. Pinedale moraines around Boulder Lake

County: Sublette.
Lat 42°50′ N.; long 109°40′ W.
Number of photographs: 4.
Photograph scale: 1:60,300.
Focal length: 6 in.
Date flown: June 21, 1954.
Map reference: U.S. Geol. Survey Lander sheet, scale scale 1:250,000.
Geology reference: Holmes, G. W., and Moss, J. H., 1955, Pleistocene geology of the southwestern Wind River Mountains, Wyoming: Geol. Soc. America Bull., v. 66, p. 629–654; see pls. 2 and 3.

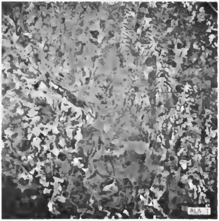
Features illustrated (set nos. Wyo. 8 A–D in northeast corner of photographs).—A spectacular display of moraines surrounds Boulder Lake. The moraines terminate in a broad outwash apron. They lie on and are derived in large part from weak clay and sand of Tertiary age. The moraines end abruptly where they pass onto the Precambrian igneous and metamorphic rocks of the southwestern part of the Wind River Mountains.

Wyo. 9. Anticlines near Little Medicine Bow River

County: Carbon.
Lat 41°58′ N.; long 106°16′ W.
Number of photographs: 3.
Photograph scale: 1:27,700.
Focal length: 5.1 in.
Date flown: June 14, 1947.
Map reference: U.S. Geol. Survey Saddleback Hills and Como Ridge 15-min quadrangles, scale 1:62,500.
Geology reference: Dobbin, C. E., Bowen, C. F., and Hoots, H. W., 1929, Geology and coal and oil resources of the Hanna and Carbon basins, Carbon County, Wyoming: U.S. Geol. Survey Bull. 804, 88 p.; geol. map (pl. 27), scale 1:62,500.

Features illustrated (set nos. Wyo. 9 A–C in southeast corner of photographs).—The long narrow doubly plunging anticline (near center of photograph 9 C) has a sandstone core surrounded by shale formations. Most of photograph 9 B is a westward-plunging anticline with a core of Precambrian crystalline rocks surrounded by outward-dipping sandstone cuestas separated by shale units. Just west of the Precambrian core (Pine Butte) the sedimentary rocks are locally broken by faults. Many of the individual cuestas show distinctive patterns of gullies and are offset by small cross faults. The large valleys are in shale, and rivers have meandering courses except where streams pass through or close to sandstone beds.

REPRESENTATIVE AERIAL PHOTOGRAPHS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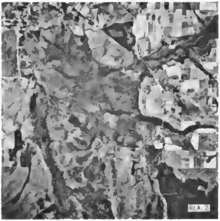
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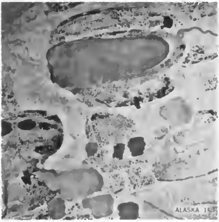
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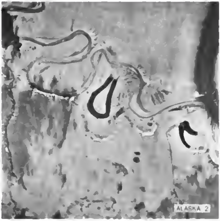
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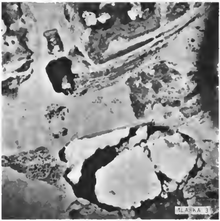
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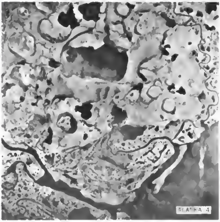
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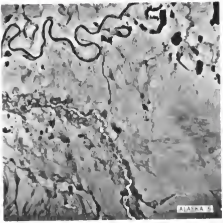
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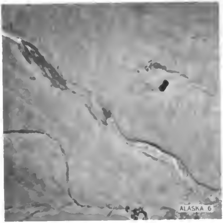
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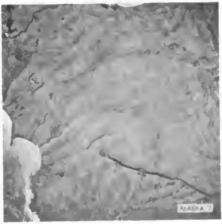
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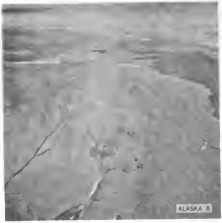
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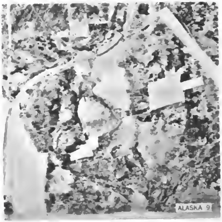
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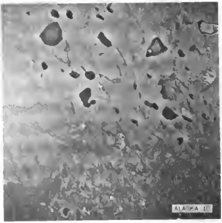
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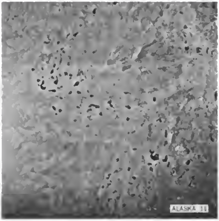
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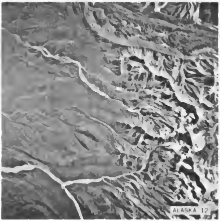
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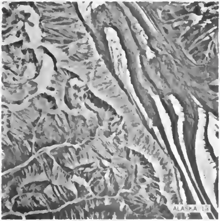
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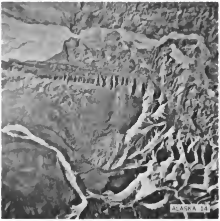
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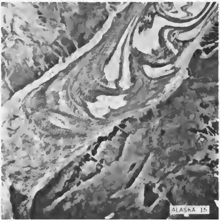
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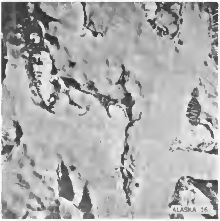
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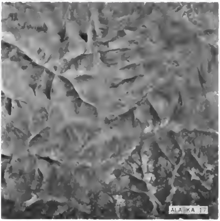
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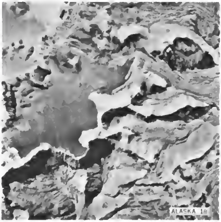
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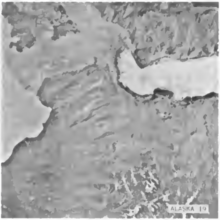
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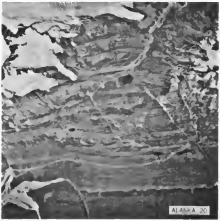
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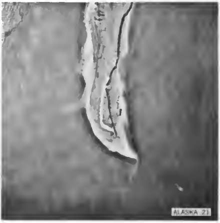
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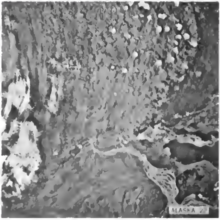
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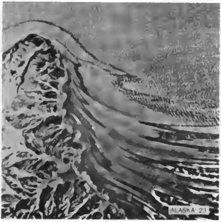
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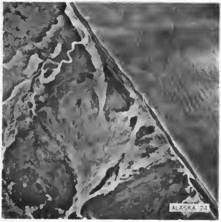
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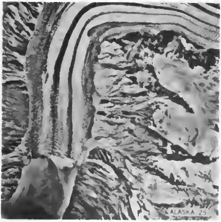
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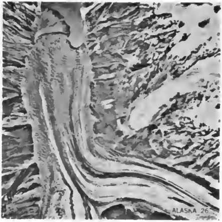
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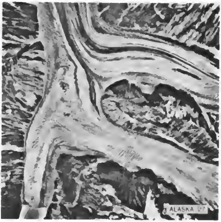
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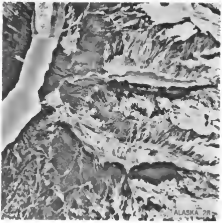
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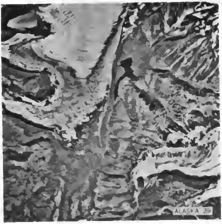
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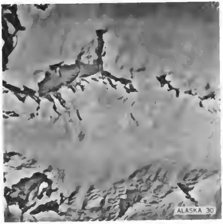
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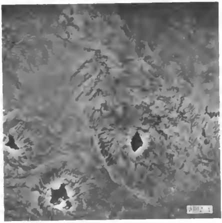
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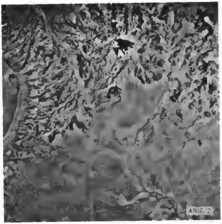
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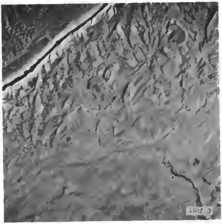
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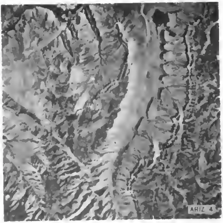
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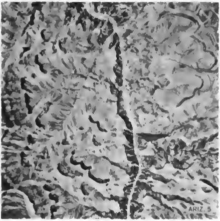

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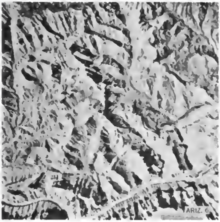

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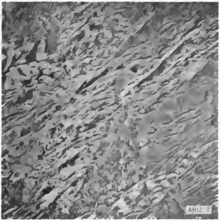

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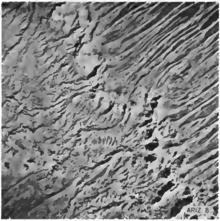

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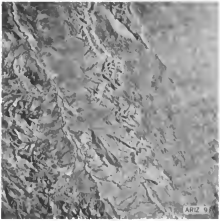

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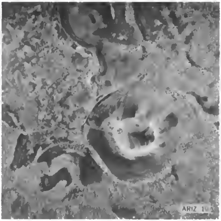

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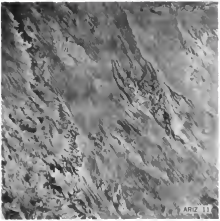
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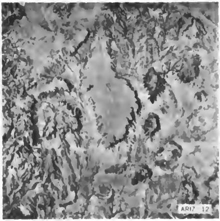
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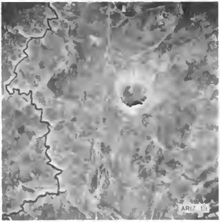
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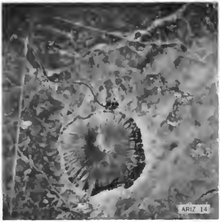
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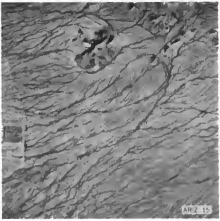
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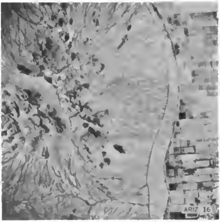
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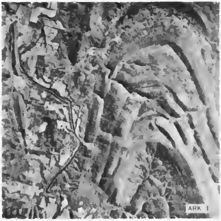
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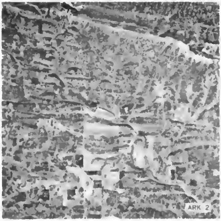
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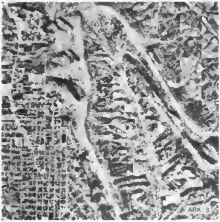
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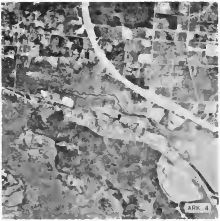
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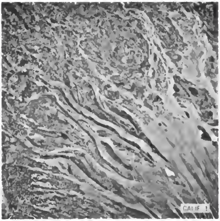
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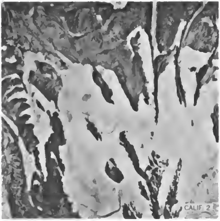
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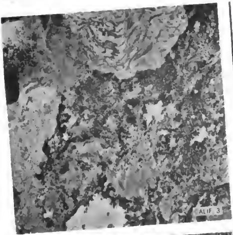
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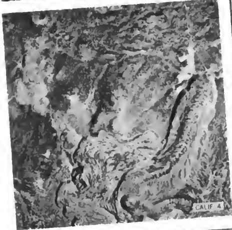
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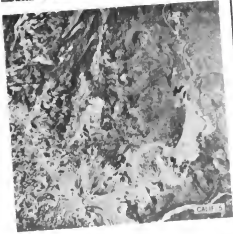
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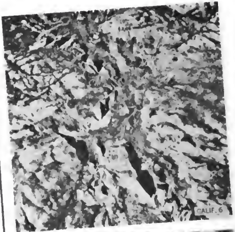
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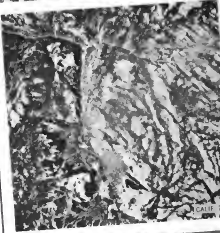
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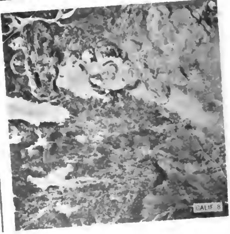
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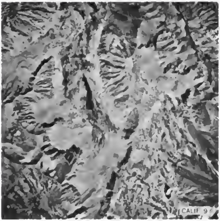
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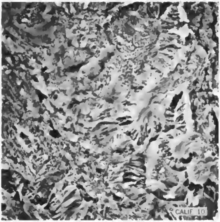
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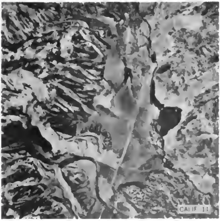
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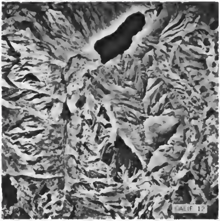
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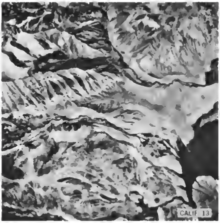
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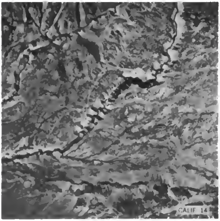
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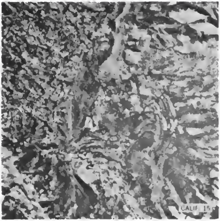
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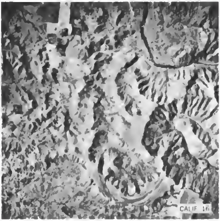
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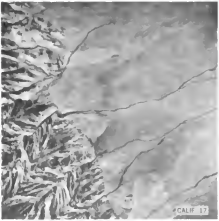
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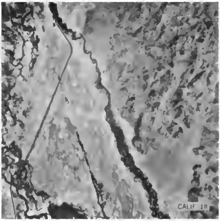
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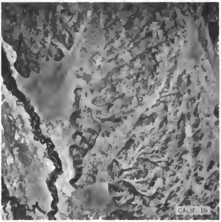
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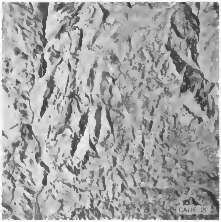
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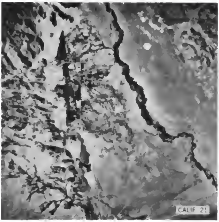
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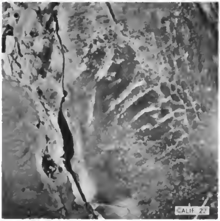
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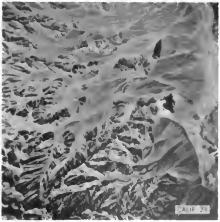
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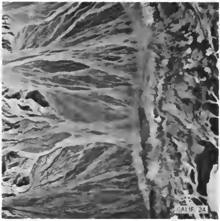
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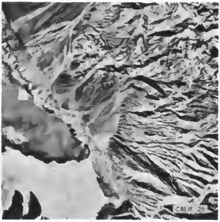
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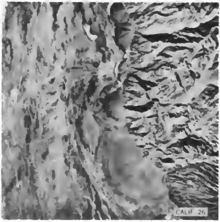
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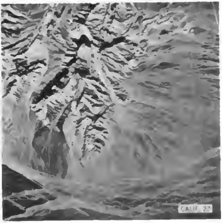
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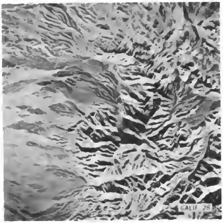
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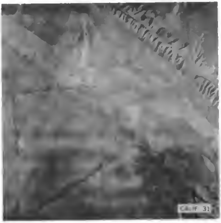
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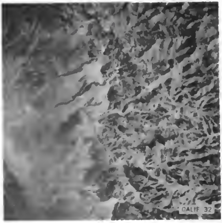
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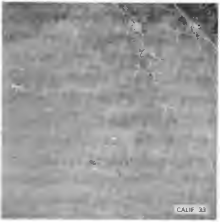
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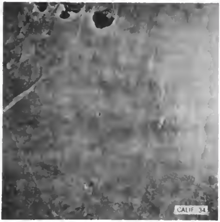
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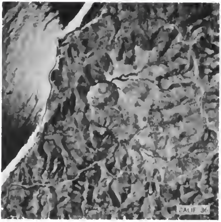
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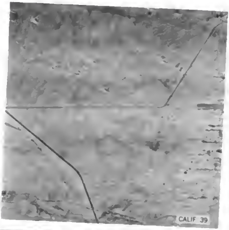

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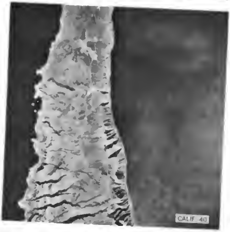

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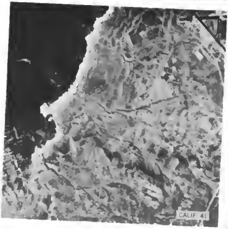

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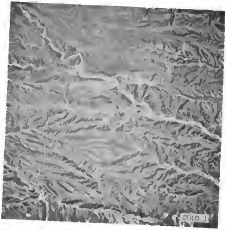

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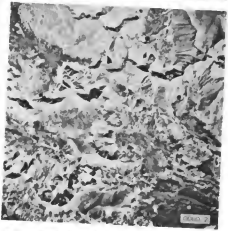

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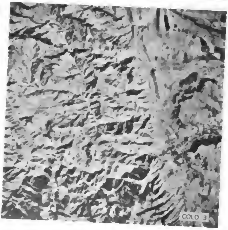

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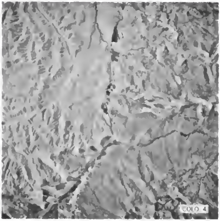
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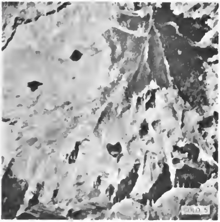
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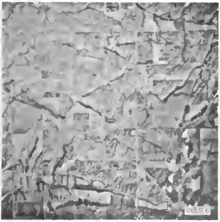
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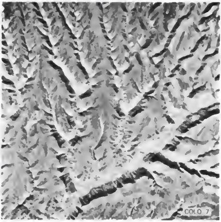
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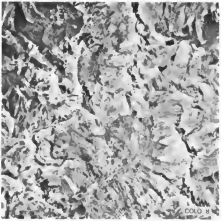
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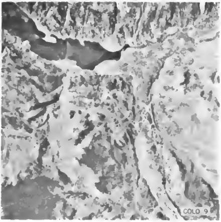
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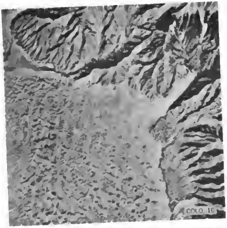
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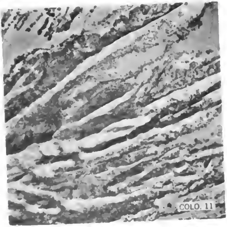
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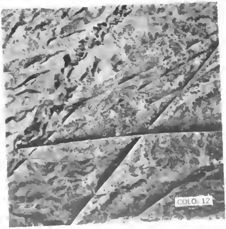
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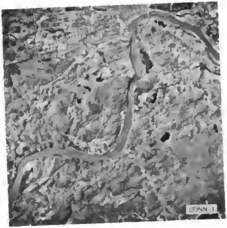
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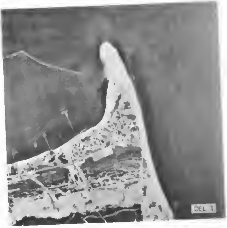
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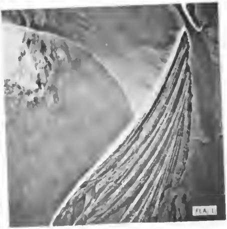
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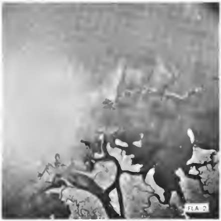

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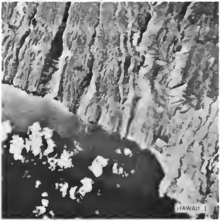

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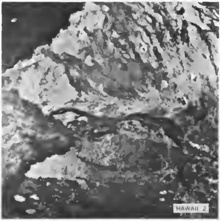

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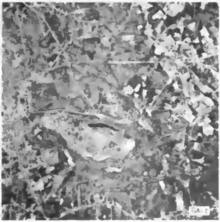

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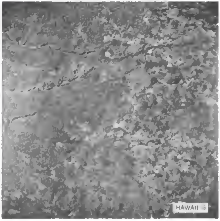

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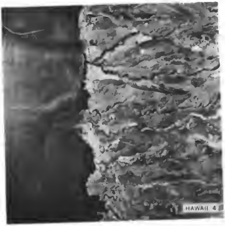
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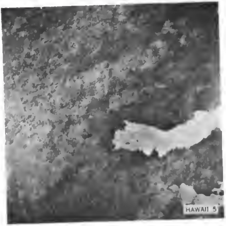
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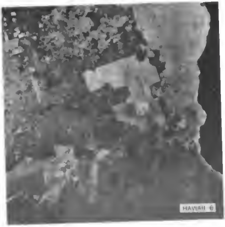
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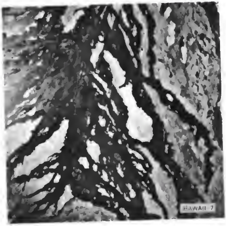
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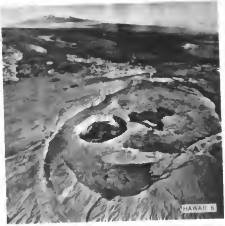
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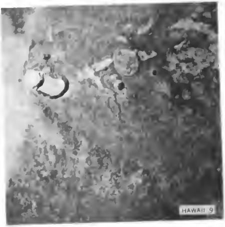
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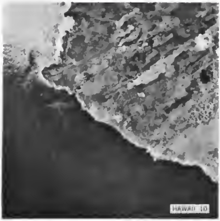

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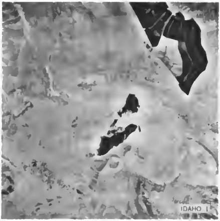

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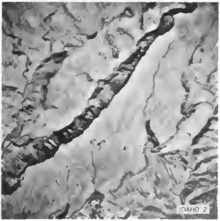

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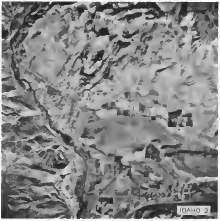

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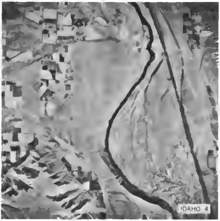

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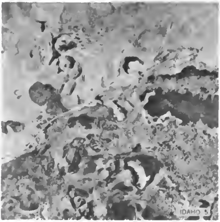

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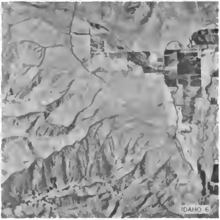
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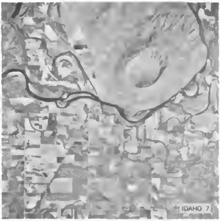
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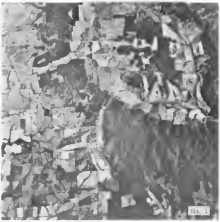
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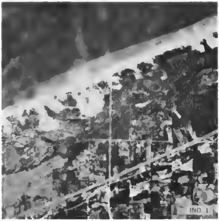
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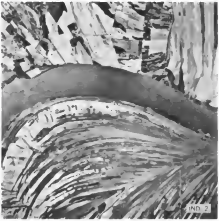
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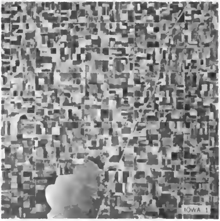
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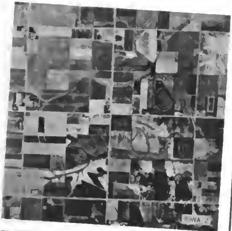
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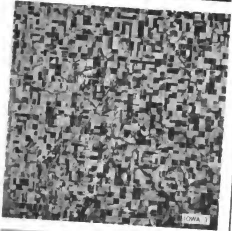
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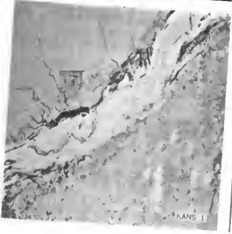
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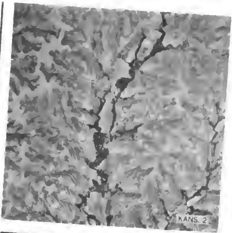
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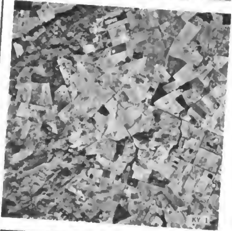
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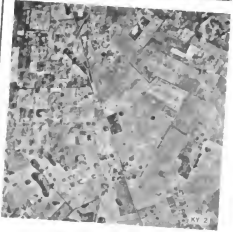
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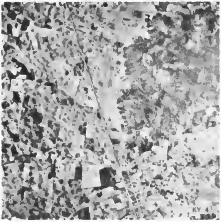
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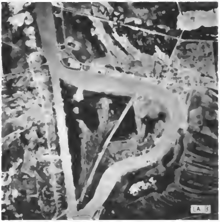
LA 2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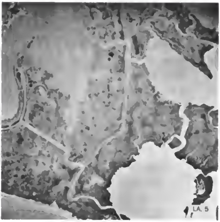

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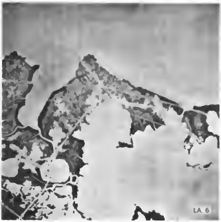

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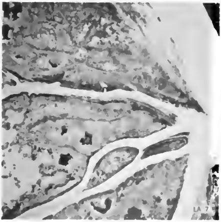

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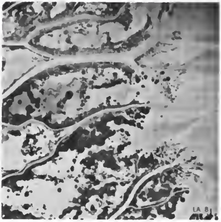

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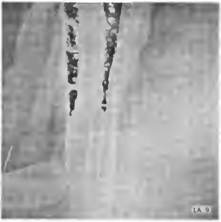

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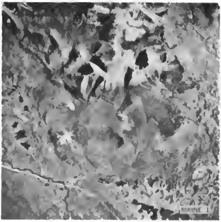

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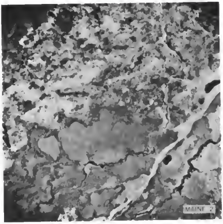

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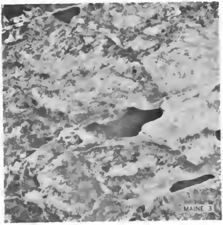

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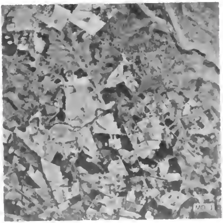

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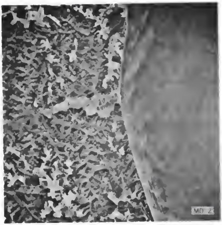

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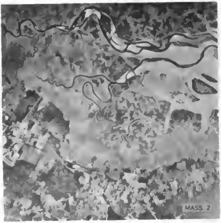

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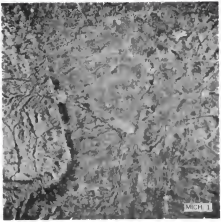
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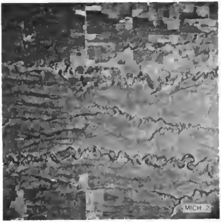
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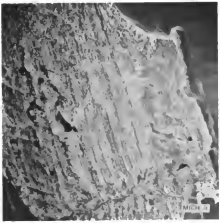
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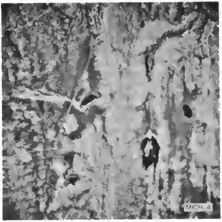
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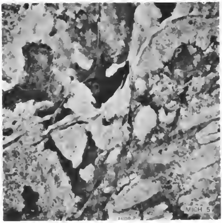
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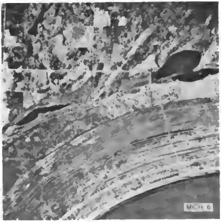
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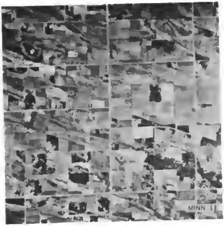

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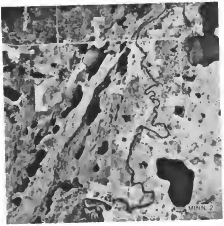

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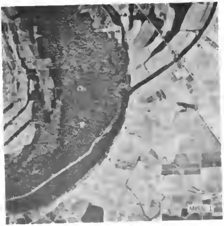

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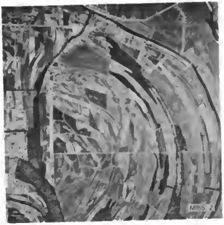

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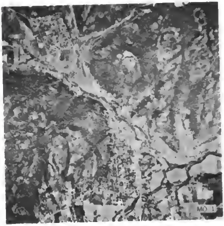

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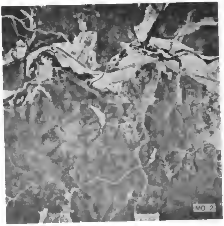

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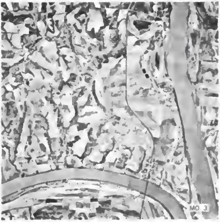

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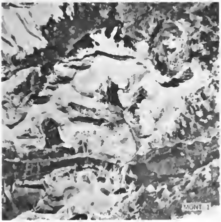

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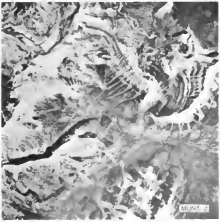

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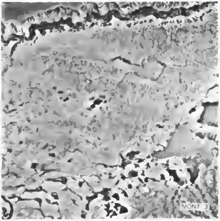

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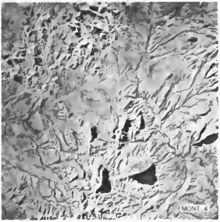

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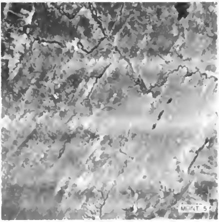

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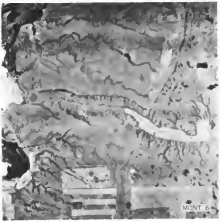

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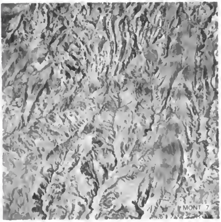

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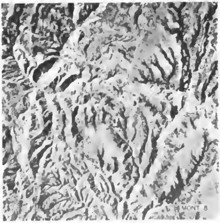

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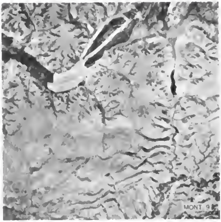

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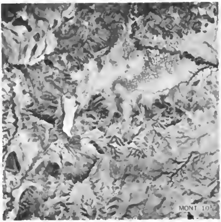

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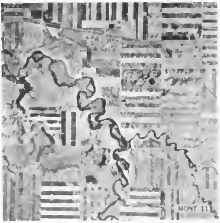

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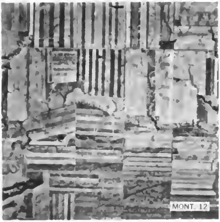

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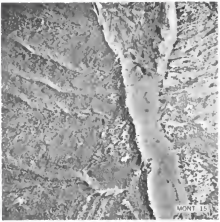

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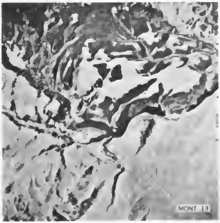

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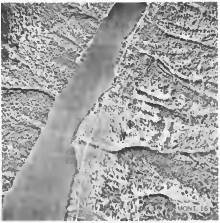

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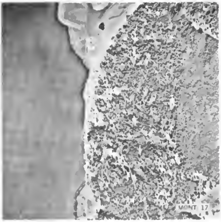

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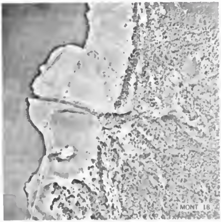
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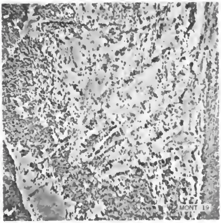
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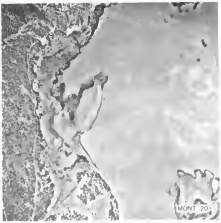
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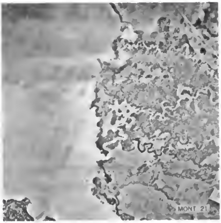
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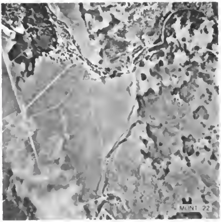
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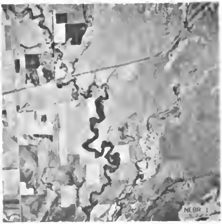
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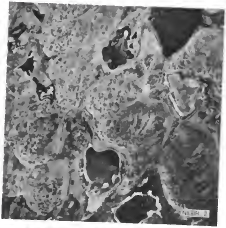
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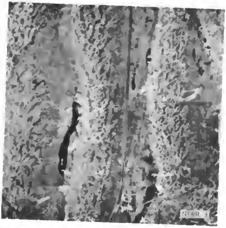
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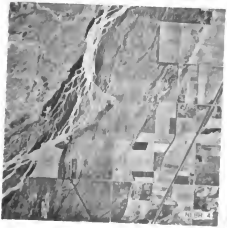
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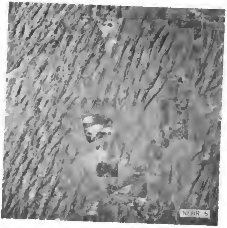
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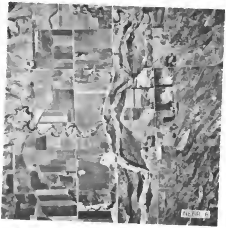
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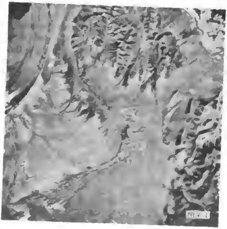
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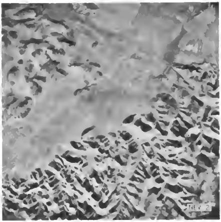
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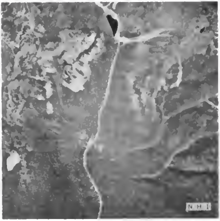
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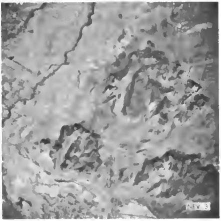
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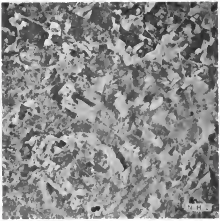
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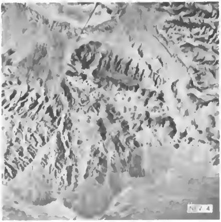
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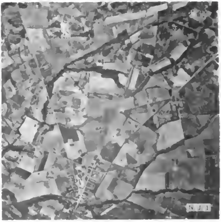
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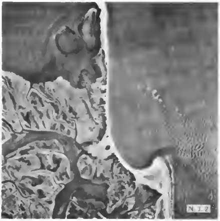
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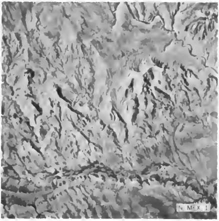
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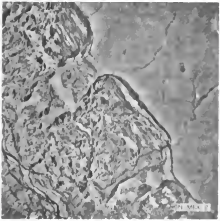
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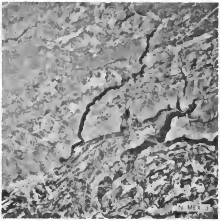
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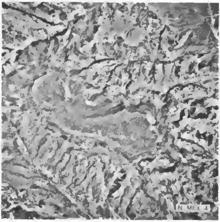
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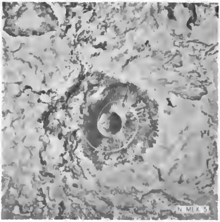
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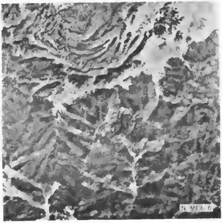
N. Mex. 6–11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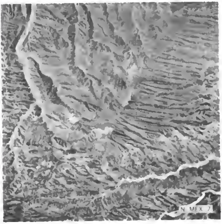
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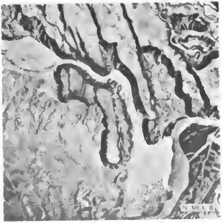
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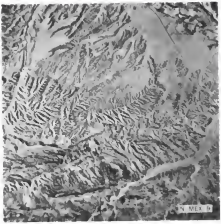
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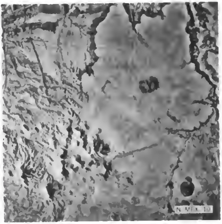
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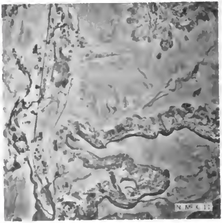
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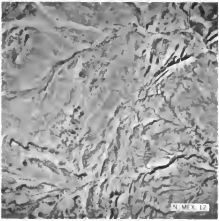
N MEX 12

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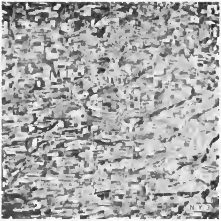
N Y 2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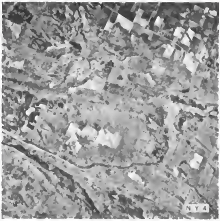
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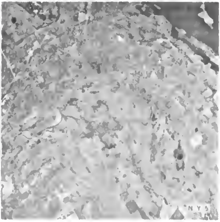
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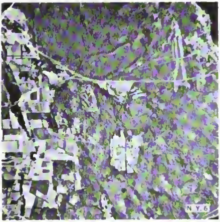
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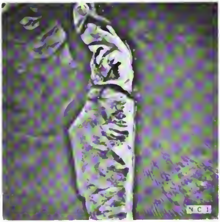
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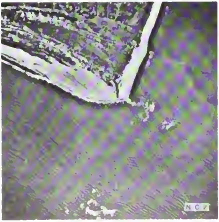
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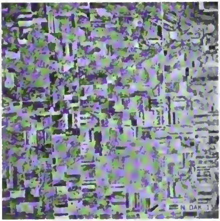
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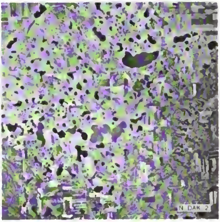
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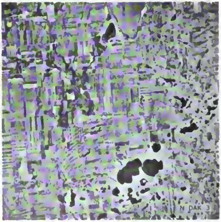
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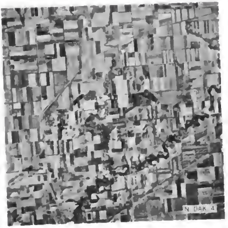
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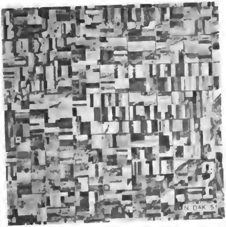
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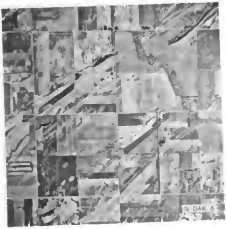
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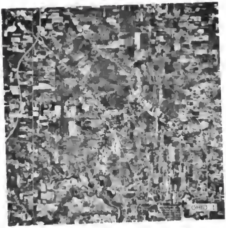
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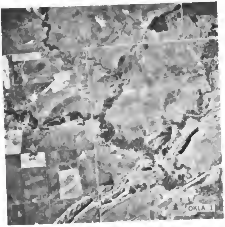
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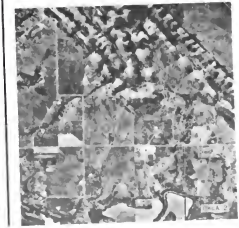
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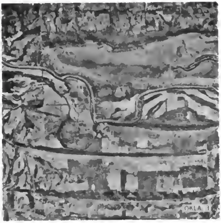
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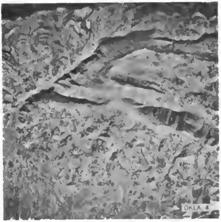
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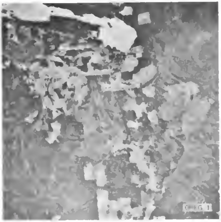
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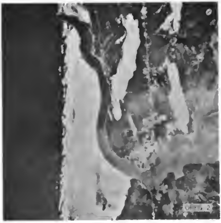
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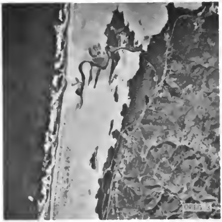
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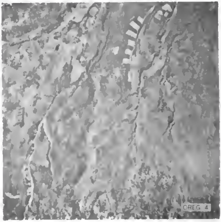
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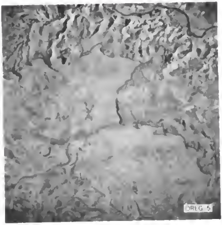
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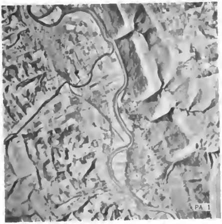
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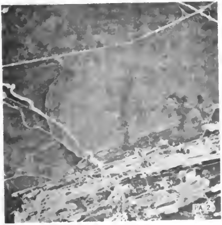
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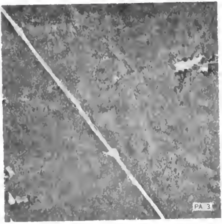
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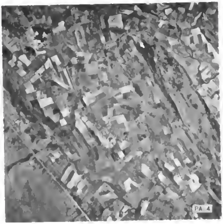
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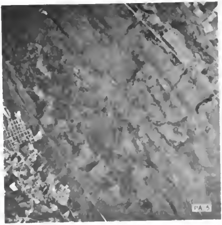
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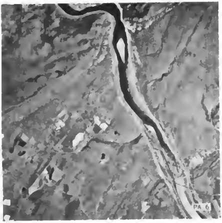
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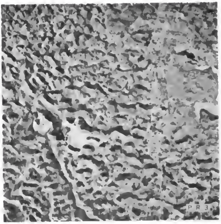
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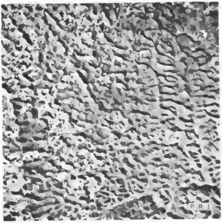
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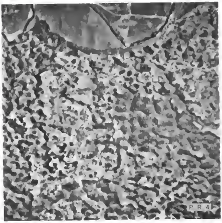
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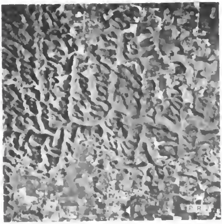
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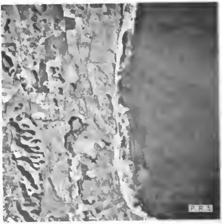
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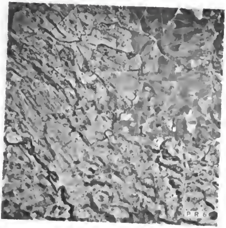
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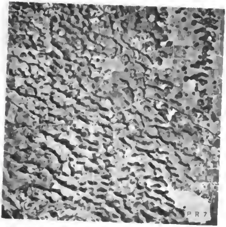
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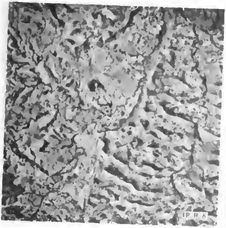
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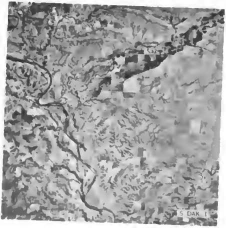
S.C 1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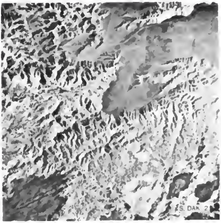
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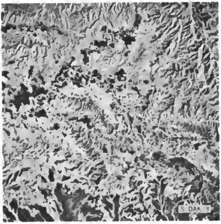
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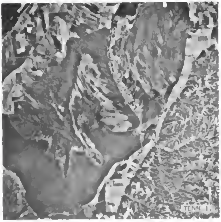
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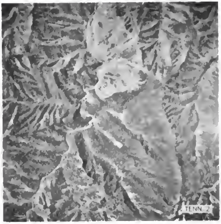
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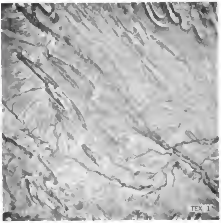
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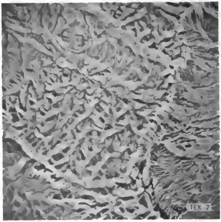
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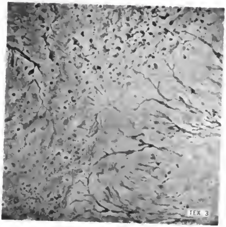

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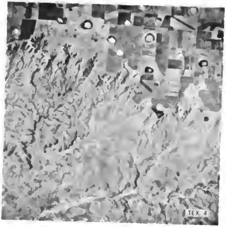

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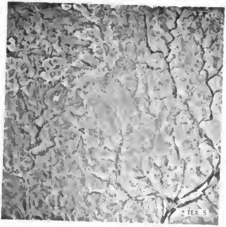

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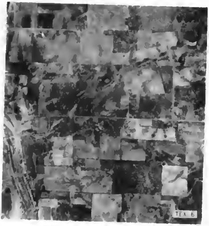

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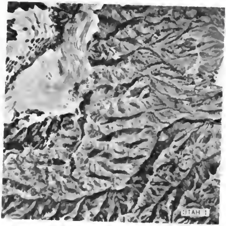

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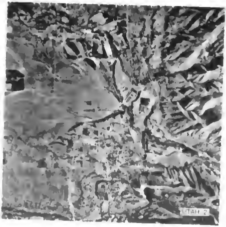

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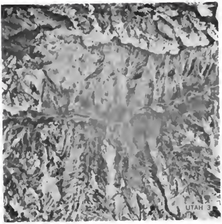
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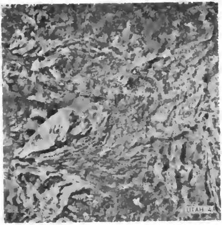
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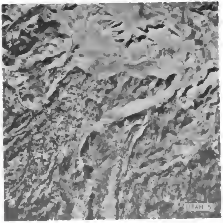
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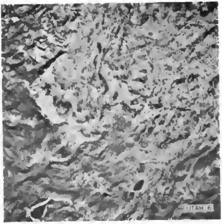
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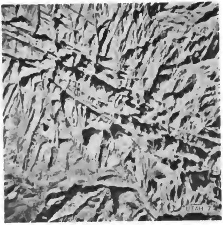
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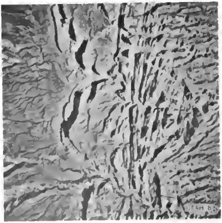
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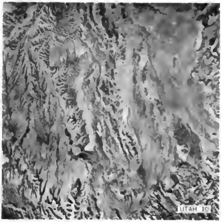
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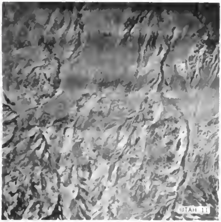
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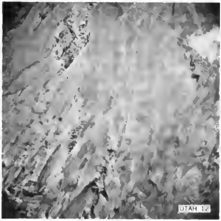
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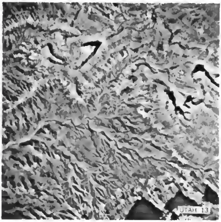
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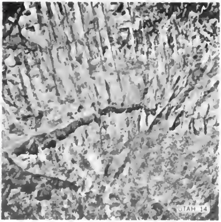
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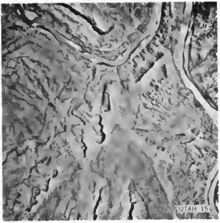
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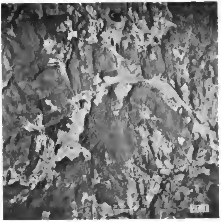
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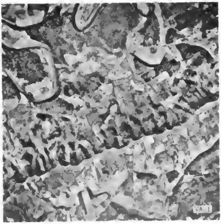
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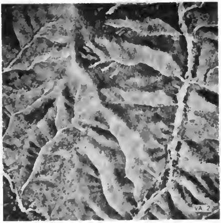
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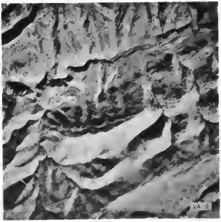
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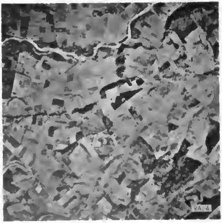
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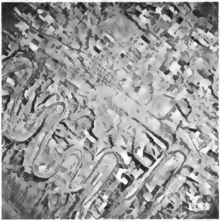
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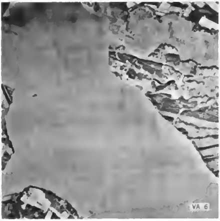
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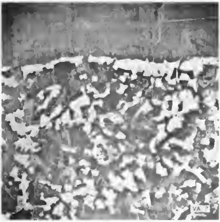
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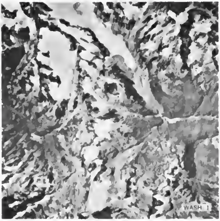
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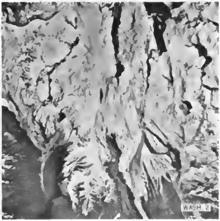
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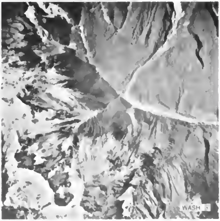
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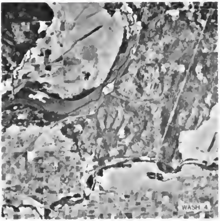
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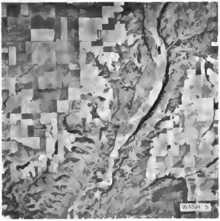
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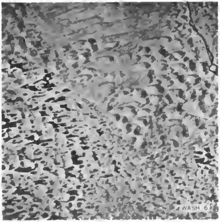
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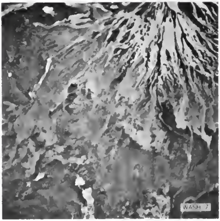
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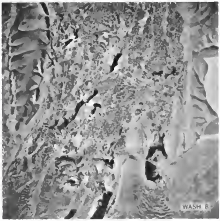
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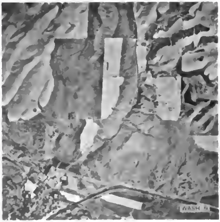
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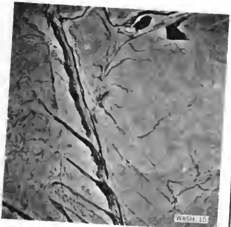
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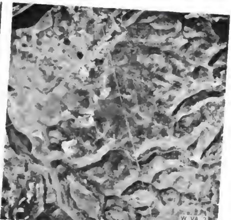
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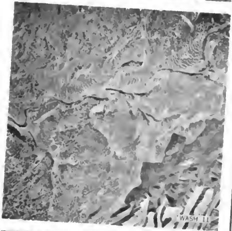
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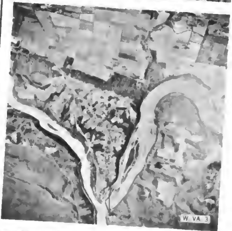
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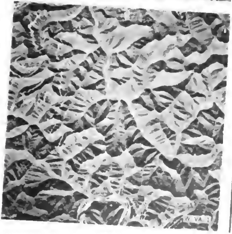
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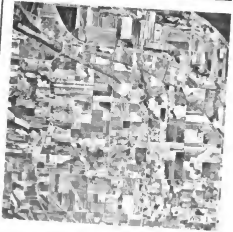
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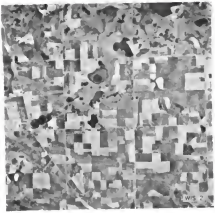
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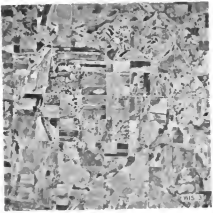
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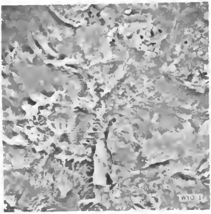
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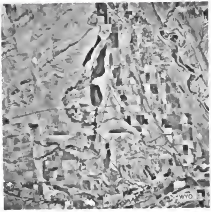
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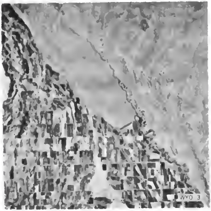
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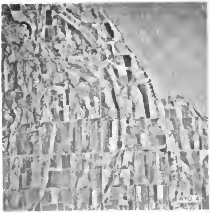
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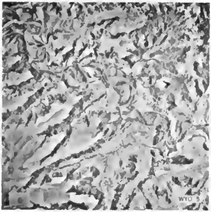

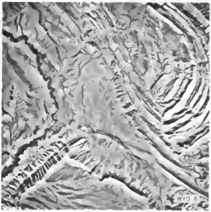

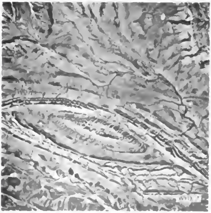

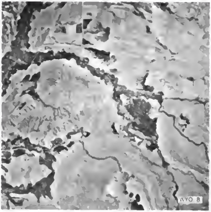

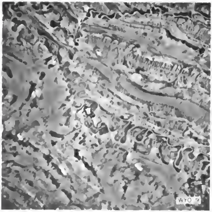

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A DESCRIPTIVE CATALOG OF

SELECTED AERIAL PHOTOGRAPHS OF GEOLOGIC FEATURES IN AREAS OUTSIDE THE UNITED STATES

U.S. DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY
PROFESSIONAL PAPER 591

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A Descriptive Catalog of Selected Aerial Photographs of Geologic Features in Areas Outside the United States

Assembled by CHARLES R. WARREN, DWIGHT L. SCHMIDT, CHARLES S. DENNY, *and* WILLIAM J. DALE

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Assembled by Charles R. Warren, Dwight L. Schmidt,
Charles S. Denny, and William J. Dale

INTRODUCTION

The U.S. Geological Survey has selected and assembled 67 sets of aerial photographs that illustrate a variety of geologic features in Antarctica, South and Central America, the southwest Pacific, Iran, Japan, the Arabian Peninsula, Pakistan, and mainland China. Contact prints of the photographs composing these sets are available for purchase. Sets of photographs of geologic features in the United States and Puerto Rico are listed in a separate catalog (Denny, C. S., and others, 1968, A descriptive catalog of selected aerial photographs of geologic features in the United States: U.S. Geol. Survey Prof. Paper 590).

Each set described here consists of one to five photographs. Most sets except those of Antarctica consist of vertical photographs and provide stereoscopic coverage. Most of the Antarctic sets are single oblique photographs taken as part of the U.S. Antarctic Research Program sponsored by the National Science Foundation. The photographs have been selected from pictures submitted by Geological Survey geologists and from other sources.

This catalog gives, for each set of photographs, the location, the scale of the photography, and a brief description of the features illustrated; the location is also shown on an accompanying map (pl. 1). For many of the sets, a reference is given to a topographic map that covers the area shown and to a geologic map or report that describes it. The first photograph (photograph A) of each set is also reproduced at a reduced scale at the end of the report. The catalog is set up on a geographic basis; the 67 sets are listed alphabetically by country or region. An index to the various geologic features and to the areas shown in the photographs is included.

HOW TO ORDER PHOTOGRAPHS

The photographs listed in this catalog can be ordered from the Map Information Office, U.S. Geological Survey, General Services Administration Building, Washington, D.C. 20242. Each order should give the locality name and number—for example, Antarctica 7, Bikini 2, Iran 5. No further identification is necessary. An order blank is included in the pocket of this publication. Also included in the pocket is a form to be used in ordering any geologic or topographic maps produced by the Geological Survey and referred to in this publication. Prepayment is required, and the amount of remittance, made by check or money order payable to the U.S. Geological Survey, will depend upon the number of prints and maps ordered. The prices are subject to change, but the following prices for 9- by 9-inch contact prints, in effect at the time of publication, will serve as a guide to the purchaser: 1 to 5 prints, \$1 each; 6 to 100 prints, 90 cents each; more than 100 prints, 70 cents each.

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DETAILED DESCRIPTIONS OF SETS OF AERIAL PHOTOGRAPHS

Antarctica 1. East side of Sentinel Range and Edith Ronne Ice Shelf

Area: Sentinel Range.
Lat 78°20′ S.; long 84° W.
Number of photographs: 1.
Photograph scale (foreground): About 1:35,000.
Focal length: 6 in.
Date flown: Dec. 15, 1959.
Map reference: U.S. Geol. Survey Vinson Massif and Newcomer Glacier sheets, Antarctica, 1962, scale 1:250,000.
Geology reference: Craddock, Campbell, and Webers, G. F., 1964, Fossils from the Ellsworth Mountains, Antarctica: Nature, v. 20, p. 174–175.

Features illustrated.—Looking north-northwest along the east edge of the Sentinel Range (left) and an arm of the Edith Ronne Ice Shelf (right) toward Ellsworth Land (skyline). The relief on the east side of the range is only several hundred meters in contrast to several thousand meters on the west side. (See Antarctica 2.) Ice from within the range flows eastward into the Ronne drainage system whose flow is toward the viewer. The local ice streams from the mountains retain their identity on the ice shelf for many tens of miles downstream.

This eastern edge of the range is composed of folded slate, quartzite, and graywacke; the youngest strata contain a glossopterid flora of Permian age. Older Paleozoic metasedimentary rocks underlie other parts of the range.

Antarctica 2. Mile-high escarpment on west side of Sentinel Range

Area: Sentinel Range.
Lat 78°25′ S.; long 86° W.
Number of photographs: 1.
Photograph scale (foreground): About 1:20,000.
Focal length: 6 in.
Date flown: Dec. 15, 1959.
Map reference: U.S. Geol. Survey Vinson Massif sheet, Antarctica, 1962, scale 1:250,000.
Geology reference: Craddock, Campbell, Anderson, J. J., and Webers, G. F., 1964, Geologic outline of the Ellsworth Mountains, *in* Adie, R. J., ed., Antarctic geology: New York, John Wiley and Sons, p. 155–170.

Features illustrated.—Looking north from the west flank of the Vinson Massif (off right foreground) along the sheer west front of the Sentinel Range toward Ellsworth Land (skyline). From the west-facing escarpment at altitudes of about 4,000–5,000 meters, the crest of the range declines eastward to about 500 meters. West of the range, the plateau ice flows northward away from the viewer. Mount Tyree, altitude 4,965 meters, is the highest peak in the photograph (top center). Deformed quartzites of Paleozoic age underlie the west escarpment and most of the visible mountains.

Antarctica 3. Deformed quartzite in west face of Mount Tyree, Sentinel Range

Area: Sentinel Range.
Lat 78°25′ S.; long 86° W.
Number of photographs: 1.
Photograph scale (foreground): About 1:16,000.
Focal length: 6 in.
Date flown: Dec. 15, 1959.
Map reference: U.S. Geol. Survey Vinson Massif sheet, Antarctica, 1962, scale 1:250,000.
Geology reference: Craddock, Campbell, Anderson, J. J., and Webers, G. F., 1964, Geologic outline of the Ellsworth Mountains, *in* Adie, R. J., ed., Antarctic geology: New York, John Wiley and Sons, p. 155–170.

Features illustrated.—Looking east over Mount Tyree, altitude 4,965 meters, across the 50-kilometer-wide Sentinel Range to the Edith Ronne Shelf. Mount Tyree is part of the mile-high escarpment that forms the west side of the range whose summits decrease in height eastward to only a few hundred meters. Ice drains from areas of local accumulation within the range to the Edith Ronne Ice Shelf. Mount Tyree is composed of Crashsite Quartzite, a well-bedded metasandstone of Paleozoic age. Sharp folds and crenulations, joint sets, and faults are visible on the mountain face. Younger Paleozoic formations underlie the east side of the range.

Antarctica 4. Scott Glacier and polar ice plateau, Queen Maud Mountains

Area: Queen Maud Mountains.
Lat 86° S.; long 151° W.
Number of photographs: 1.
Photograph scale (foreground): About 1:45,000.
Focal length: 6 in.
Date flown: Dec. 9, 1960.
Map reference: U.S. Geol. Survey Nilsen Plateau sheet, Antarctica, 1967, scale 1:250,000. Am. Geog. Soc., Antarctica, 1965, scale 1:5,000,000.
Geology reference: Gould, L. M., 1935, Structure of the Queen Maud Mountains, Antarctica: Geol. Soc. America Bull. v. 46, p. 973–983. Doumani, G. A., and Minshew, V. H., 1965,

General geology of the Mount Weaver area, Queen Maud Mountains, Antarctica, *in* Hadley, J. B., ed., Geology and paleontology of the Antarctic: Am. Geophys. Union Antarctic Research Ser. v. 6, p. 127–144.

Features illustrated.—Looking south up Scott Glacier to the polar ice plateau, altitude about 3,000 meters, on skyline. This rapidly moving outlet glacier drains from the plateau ice sheet through the Queen Maud Mountains to the Ross Ice Shelf (off photograph to right). Snow covers much of the intensely crevassed ice stream, although median shear zones along the joins of various tributary glaciers are not sufficiently covered to completely obliterate the underlying rough ice surface. The glacially eroded, pyramid-shaped mountains in the foreground and middle distance are underlain by deformed quartzite, slate, schist, and gneiss and by intrusive granitic rock, all of probable late Precambrian and early Paleozoic age. The broad-topped mountains (right and left background) are underlain by flat-lying sandstone of Devonian(?) to Permian age and contain thick dolerite sills of probable Jurassic age. The sandstone and dolerite dip gently southward (away from viewer) and unconformably overlie the older rocks.

Antarctica 5. Flow lines and crevasses near head of Shackleton Glacier, Queen Maud Mountains

Area: Queen Maud Mountains.
Lat 85° S.; long 177° W.
Number of photographs: 1.
Photograph scale (foreground): About 1:45,000.
Focal length: 6 in.
Date flown: Nov. 25, 1960.
Map reference: U.S. Geol. Survey Shackleton Glacier and Liv Glacier sheets, Antarctica, 1967, scale 1:250,000.
Geology reference: Gould, L. M., 1935, Structure of the Queen Maud Mountains, Antarctica: Geol. Soc. America Bull., v. 46, p. 973–983. Wade, F. A., Yeats, V. L., Everett, J. R., Greenlee, D. W., La Prade, K. E., and Shenk, J. C., 1965, Geology of the central portion of the Queen Maud Range, Transantarctic Mountains: Science, v. 150, p. 1808–1809.

Features illustrated.—Looking south-southwest up Shackleton Glacier to polar ice plateau (left skyline) and Dominion Range (right skyline) at head of Beardmore Glacier. Shackleton Glacier has an intensely crevassed surface that is typical of such rapidly moving outlet glaciers. The many flow lines are median shear zones between ice of the many tributary glaciers and that of the main stream. The lenticular disruption of the main ice stream (left center) is caused by a buried rock mass that splits the main channel beneath the surface ice. Disruptions of flow lines downstream (center) are structures within the ice that are exposed at the surface by ablation. The surface pattern has been further modified by local melting and freezing. Flat-lying strata of the Beacon Group (dark gray), here of Devonian to Permian age, and sills of Ferrar Dolerite (black) of Jurassic age form broad tabular mountains so typical of the interior side of the Transantarctic Mountains. The horizontal strata in the mountain in the right foreground are underlain by metasedimentary or granitic rocks of late Precambrian and early Paleozoic age.

Antarctica 6. Moraines on Plunket Point between Beardmore and Mill Glaciers, Queen Maud Mountains

Area: Queen Maud Mountains.
Lat 85° S.; long 167° E.
Number of photographs: 1.
Photograph scale (foreground): About 1:30,000.
Focal length: 6 in.
Date flown: Nov. 17, 1960.
Map reference: U.S. Geol. Survey, Plunket Point and The Cloudmaker sheets, Antarctica, 1967, scale 1:250,000.
Geology reference: Oliver, R. L., 1964, Geological observations at Plunket Point, Beardmore Glacier *in* Adie, R. J., ed., Antarctic geology: New York, John Wiley and Sons, p. 248–258. Grindley, G. W., McGregor, V. R., and Walcott, R. I., 1964, Outline of the geology of the Nimrod-Beardmore-Axel Heiberg Glaciers region, Ross Dependency, *in* Adie, R. J., ed., Antarctic geology: New York, John Wiley and Sons, p. 206–219.

Features illustrated.—Looking northeast down Beardmore Glacier (left) from Plunket Point (center) to the Commonwealth Range (skyline). Mill Glacier (middle right) joins the Beardmore below Plunket Point. These two outlet glaciers drain from the polar-ice plateau (behind the viewer). Surface ablation strongly accentuates the crevasses and flow lines. The median shear zone downglacier from Plunket Point and the two parallel shear zones along the left side of Plunket Point contain many small frozen lakes caused by intense ablation.

Plunket Point is covered with drift. Parallel recessional moraines, ice-marginal channels, and kames and kettles are conspicuous. Patterned ground is well developed on the lower slopes. A small ice tongue (right foreground) has left recessional moraines on the adjacent valley sides.

The Beacon Group, here of Devonian to Permian age, and intrusive sills of Ferrar Dolerite of Jurassic age underlie the massive tabular mountains across Mill Glacier and downglacier on the east side of the Beardmore Glacier.

Antarctica 7. Ice-covered slopes of mountains near the lower Beardmore Glacier

Area: Holland Range.
Lat 83°15′ S.; long 167° E.
Number of photographs: 1.
Photograph scale (foreground): About 1:25,000.

Focal length: 6 in.
Date flown: Nov. 6, 1960.
Map references: U.S. Geol. Survey, Mount Elizabeth and Mount Rabot sheets, Antarctica 1966, and The Cloudmaker and Buckley Island sheets, Antarctica 1967, scale 1:250,000.
Geology reference: Grindley, G. W., 1963, Geology of the Queen Alexandra Range, Beardmore Glacier, Antarctica: New Zealand Jour. Geology and Geophysics, v. 6, no. 3, p. 307–347.

Features illustrated.—Looking southwest across the Hewitt Glacier (foreground) and sheer ice slopes of the Holland Range (middle) to the Bowden Névé (back center). The Bowden Névé drains to the left down a rough ice fall of the Lennox-King Glacier (upper left). Beyond is the Grindley Plateau (left skyline) and the high peak of Mount Kirkpatrick (4,528 meters) in the Queen Alexandra Range. To the right over Mount Miller (4,160 meters) is the Prince Andrew Plateau (right background) of the Queen Elizabeth Range.

The slopes of the Holland Range are being vigorously eroded by ice. Some small glaciers are fed by local icecaps, as in the middle ground, whereas some of the ridge and cirque ice is nourished entirely by snow accumulation upon the slopes. The broad flat-topped mountains and plateaus in the background are underlain by flat-lying strata of the Beacon Group, here of Devonian to Triassic age and intruded by sills of Jurassic dolerite. In the upper Alexandra Range, abundant flat-lying flood basalts of Jurassic age make the top of the sedimentary section.

Antarctica 8. Crevasses and seracs on Byrd Glacier, Britannia Range

Area: Britannia Range.
Lat 80°15′ S.; long 158° E.
Number of photographs: 1.
Photograph scale (foreground): About 1:25,000.
Focal length: 6 in.
Date flown: Nov. 14, 1956.
Map reference: U.S. Geol. Survey Mount Olympus and Cape Selborne sheets, Antarctica, 1966, scale 1:250,000.
Geology reference: Swithinbank, C. W. M., 1963, Ice movement of valley glaciers flowing into the Ross Ice Shelf, Antarctica: Science, v. 141, no. 3580, p. 523–524. Haskell, T. R., Kennett, J. P., and Prebble, W. M., 1964, Basement and sedimentary geology of the Darwin Glacier area, *in* Adie, R. J., ed., Antarctic geology: New York, John Wiley and Sons, p. 348–351.

Features illustrated.—Looking west up Byrd Glacier along the south flank of Britannia Range (right) to the polar ice plateau. Byrd Glacier has the fastest rate of flow of any measured glacier in Antarctica; its surface movement is slightly less than 2.5 meters per day. The strong surface lines are median shear zones between main-stream ice and tributary ice. These zones are readily discernible on the photograph despite extremely abundant crevasses and seracs.

The hills to the right of the glacier are granitic rocks of probable early Paleozoic age unconformably overlain by flat-lying strata of the Beacon Group of late Paleozoic age (center and right skyline). Intrusive sills of the Ferrar Dolerite of probable Jurassic age occur in the section.

Antarctica 9. Glacier tongue and sea ice near Okuma Bay, Ross Ice Shelf

Area: Edward VII Peninsula.
Lat 77°30′ S.; long 156° W.
Number of photographs: 1.
Photograph scale (foreground): About 1:7,000.
Focal length: 6 in.
Date flown: Oct. 25, 1961.
Map reference: U.S. Geol. Survey Saunders Coast-Marie Byrd Land, Antarctica Sketch Map, 1968, scale 1:500,000. Am. Geog. Soc., Antarctica, 1965, scale 1:5,000,000.
Geology reference: Gould, L. M., 1949, Glaciers of Antarctica: Am. Philos. Soc. Proc., v. 82, no. 5, p. 836–860.

Features illustrated.—Looking southeast across the mouth and floating ice tongue of an unnamed glacier draining the low-lying ice-covered west coast of Edward VII Peninsula (background). In many respects this 14-kilometer-wide tongue resembles the barrier front of the nearby Ross Ice Shelf which is about 30 meters high and moves 1–2 meters per day. The broad longitudinal swales (backcenter) are hinge-line depressions that roughly parallel the coast line and are formed by tidal action. At and near the ice front, a secondary set of hinge lines result in sharply crevassed domes. Several small icebergs (upper right), detached from the glacier front, are frozen in the sea ice. This photograph, taken in the spring, shows the breaking up of 1-year-old sea ice (light gray). In some of the openings, new ice (dark gray) has formed during intermittent periods of cold.

Antarctica 10. Ice deformation on Ross Ice Shelf at Ross Island

Area: Ross Island.
Lat 77°50′ S.; long 167° E.
Number of photographs: 1.
Photograph scale: 1:2,500.
Focal length: 6 in.
Date flown: Feb. 15, 1960.
Map reference: U.S. Geol. Survey Ross Island sheet, Antarctica, 1965, scale 1:250,000.
Geology reference: Hochstein, M. P., 1967, Pressure ridges of the McMurdo Ice Shelf near Scott Base, Antarctica: New Zealand Jour. Geology and Geophysics, v. 10, no. 4, p. 1165–1168. Heine, A. J., 1967, The McMurdo Ice Shelf, Antarctica: New Zealand Jour. Geology and Geophysics, v. 10, no. 2, p. 474–478.

Features illustrated (set no. Antarctica 10 in south corner of photograph).—En echelon anticlines and synclines in floating ice (north corner) have an average wavelength of 60 meters. The undulations terminate against thrust faults where the ice is grounded on shore of Ross Island (shadow of island in west corner). The faults are delineated by jagged pressure ridges (center to south corner). Deformation occurs along a zone less than 1 kilometer wide by about 2 kilometers long (see Antarctica 12) where the floating Ross Ice Shelf (main shelf to east) presses against Ross Island. Local ice movement is to west-southwest. Tensional crevasse patterns are seen along the crests of the anticlines. Scott Base (New Zealand) is just off the photograph to the southwest. Scale is indicated by vehicular road with one vehicle near the midpoint. Several dozen Weddell seals, masked in shadow, and seal tracks are visible among the pressure ridges.

Antarctica 11. Craters of Mount Erebus, Ross Island

Area: Ross Island.
Lat 77°30′ S.; long 167° E.
Number of photographs: 1.
Photograph scale (foreground): About 1:30,000.
Focal length: 6 in.
Date flown: Nov. 22, 1960.
Map reference: U.S. Geol. Survey Ross Island and Mount Discovery sheets, Antarctica, 1965, scale 1:250,000.
Geology reference: Smith, W. C., 1954, The volcanic rocks of the Ross Archipelago: British Antarctic (*Terra Nova*) Exped., 1910, Nat. History Rept., Geology, v. 2, no. 1, 107 p.

Features illustrated.—Looking south over the 3,794-meter summit of Mount Erebus, the best known active volcano in Antarctica. A faint plume of steam is rising from one of the two summit craters. The modern summit cones fill an older, larger crater. In the foreground is the rim of a still older and larger crater. Hut Point Peninsula, extending south from Erebus, has McMurdo Station (United States) on its southern tip. Ross Island consists of basalt, trachyte, and "kenyte" of Cenozoic age.

To the right is McMurdo Sound covered mostly with 1-year-old sea ice. To the left is the Ross Ice Shelf. The floating Erebus Glacier tongue with characteristic saw-toothed edges extends westward (right) into McMurdo Sound from the base of Hut Point Peninsula.

Antarctica 12. Williams Airfield, McMurdo Station, and Hut Point Peninsula, Ross Island

Area: Ross Island.
Lat 77°50′ S.; long 167° E.
Number of photographs: 1.
Photograph scale (foreground): About 1:30,000.
Focal length: 6 in.
Date flown: Nov. 14, 1959.
Map reference: U.S. Geol. Survey Ross Island Sheet, Antarctica, 1965, scale 1:250,000.
Geology reference: Smith, W. C., 1954, The volcanic rocks of the Ross Archipelago: British Antarctic (*Terra Nova*) Exped., 1910, Nat. History Rept., Geology, v. 2, no. 1, 107 p.

Features illustrated.—Looking north-northeast across McMurdo Sound (foreground and left) to Ross Island where Mount Erebus looms on the skyline. Erebus, a stratiform volcano, is the best known active volcano on the Antarctic continent—a thin plume of steam rises from its 3,794-meter summit. Mount Terror (right skyline), 3,262 meters, and Mount Bird (left background), 1,766 meters, are also stratiform volcanoes. McMurdo Station (United States) at the landward end of the roadway (center of photograph), is on the southern tip of Hut Point Peninsula. Volcanic rocks of Cenozoic age (basalt, trachyte, and "kenyte") underlie the whole of Ross Island.

Williams Airfield (left foreground), used from 1956 to 1961, is on old sea ice about 12 meters thick. The scalloped north-facing edge (foreground) of this ice adjoins 1- to several-year-old sea ice, probably less than 5 meters thick, covering McMurdo Sound. Barrier ice of the Ross Ice Shelf (right middle ground) presses against the southern end of Hut Point Peninsula adjacent to Scott Base (New Zealand) and forms anticlines and synclines (pressure ridges, see Antarctica 10). A typically saw-toothed floating glacial tongue extends westward into McMurdo Sound from the base of Hut Point Peninsula.

Antarctica 13. Crevasses in floating tongue of Koettlitz Glacier at head of McMurdo Sound

Area: Victoria Land.
Lat 78°10′ S.; long 164° E.
Number of photographs: 1.
Photograph scale (foreground): About 1:30,000.
Focal length: 6 in.
Date flown: Dec. 19, 1957.
Map reference: U.S. Geol. Survey Mount Discovery sheet, Antarctica, 1965, scale 1:250,000.
Geology reference: Blank, H. R., Cooper, R. A., Wheeler, R. H., and Willis, I. A. G., 1963, Geology of the Koettlitz-Blue Glacier Region, Southern Victoria Land, Antarctica: Royal Soc. New Zealand Trans., v. 2, no. 5, p. 79–100. Gunn, B. M., and Warren, Guyon, 1962, Geology of Victoria Land between the Mawson and Mulock Glaciers, Antarctica: New Zealand Geol. Survey Bull. 71, 157 p.

Features illustrated.—Looking west-southwest across lower Koettlitz Glacier and adjacent ice-free foothills to the Royal Society Range (center and right skyline). Mount Lister (right) is 4,025 meters high, and sharp-peaked Mount Huggins (left of center) is 3,733 meters high. Koettlitz Glacier, which originates within the Royal Society Range (upper left), floats on the waters of McMurdo Sound from Heald Island (left of center) to foreground. The surface of the ice is extremely rough because of ablation which is aggravated by windblown dust (dark areas) that accumulates on the surface. Etching by ablation accentuates rectilinear crevasse pattern, typical of floating ice tongues and tidal action. On the valley walls, morainal ridges mark higher levels of Koettlitz Glacier. These moraines can be traced up the adjacent dry valleys such as Miers Valley (right midground), where the Koettlitz morainal ridges extend up the tributary valley to the ice-covered Lake Miers. The summit of the range consists of flat-lying strata of the Beacon Group, here of Devonian to Permian age, intruded by sills of Ferrar Dolerite (black) of Jurassic age. The lower hills below the escarpment are metasedimentary and granitic rocks of probable late Precambrian and Cambrian age.

Antarctica 14. Dry valleys of the Koettlitz Glacier area, Victoria Land

Area: Victoria Land.
Lat 78° S.; long 164° E.
Number of photographs: 1.
Photograph scale (foreground): About 1:30,000.
Focal length: 6 in.
Date flown: Dec. 6, 1956.
Map reference: U.S. Geol. Survey Mount Discovery sheet, Antarctica, 1965, scale 1:250,000.
Geology references: Blank, H. R., Cooper, R. A., Wheeler, R. H., and Willis, I. A. G., 1963, Geology of the Koettlitz-Blue Glacier Region, Southern Victoria Land, Antarctica: Royal Soc. New Zealand Trans., v. 2, no. 5, p. 79–100. Gunn, B. M., and Warren, Guyon, 1962, Geology of Victoria Land between the Mawson and Mulock Glaciers, Antarctica: New Zealand Geol. Survey Bull. 71, 157 p.

Features illustrated.—Looking west-southwest across the foothills of Koettlitz Valley (near sea level) to the high escarpment of the Royal Society Range. Mount Lister, altitude 4,025 meters, is on skyline just to the right of center. A short tongue of the Koettlitz Glacier (left foreground) extends westward up the Garwood Valley. The surface of this tongue is exceedingly rough, because of ablation which is intensified by a partial cover of dust (black stipple) blown onto the ice from the adjacent exposed rock. Concentric recessional moraines (black) on the valley floor indicate that a tongue of the Koettlitz Glacier once extended at least 8 kilometers up Garwood Valley. The modern ice tongue dams the ephemeral drainage of Garwood dry valley (middle ground) and forms a serpentine, ice-covered lake. In the upper part of this dry valley, the expanded-foot Garwood Glacier (middle right) blocks upvalley drainage and forms ice-covered Colleen Lake. Schist, marble, gneiss, and granitic rocks of possible Cambrian or late Precambrian age underlie the hills in the foreground. The escarpment of the Royal Society Range consists of flat-lying strata of the Beacon Group and Ferrar Dolerite sills resting unconformably on crystalline rocks.

Antarctica 15. Polar ice plateau and upper parts of Taylor and Ferrar Glaciers, Victoria Land

Area: Victoria Land.
Lat 78° S.; long 160° E.
Number of photographs: 1.
Photograph scale (foreground): About 1:15,000.
Focal length: 6 in.
Date flown: Dec. 22, 1958.
Map reference: U.S. Geol. Survey Taylor Glacier sheet, Antarctica, 1965 scale 1:250,000.
Geology reference: Gunn, B. M., and Warren, Guyon, 1962, Geology of Victoria Land between the Mawson and Mulock Glaciers, Antarctica: New Zealand Geol. Survey Bull. 71, 157 p. Hamilton, Warren, and Hayes, P. T., 1963, Type section of the Beacon Sandstone of Antarctica: U.S. Geol. Survey Prof. Paper 456–A, 18 p.

Features illustrated.—Looking northeast from edge of polar ice plateau to Ross Sea with Mount Erebus, altitude 3,794 meters, on skyline to right. Beyond Beacon dry valley (upper center) are the Kukri Hills (upper right) between the Ferrar Glacier to the right and the Taylor Glacier to the left. Flat-lying beds of the Beacon Group (gray), here of Devonian to Permian age, and sills of Ferrar Dolerite of Jurassic age are exposed in Beacon Valley. Metasedimentary schist and gneiss and granitic rocks of probable late Precambrian and early Paleozoic age underlie the Kukri Hills and adjacent mountains.

Antarctica 16. Ferrar Glacier, Kukri Hills, and Taylor Valley across edge of McMurdo Sound.

Area: Victoria Land.
Lat 77°40′ S.; long 163° E.
Number of photographs: 1.
Photograph scale (foreground): About 1: 30,000.
Focal length: 6 in.
Date flown: Dec. 19, 1957.
Map reference: U.S. Geol. Survey Ross Island and Taylor Glacier sheets, Antarctica, 1965, scale 1:250,000.
Geology reference: Gunn, B. M., and Warren, Guyon, 1962, Geology of Victoria Land between the Mawson and Mulock Glaciers, Antarctica: New Zealand Geol. Survey Bull. 71, 157 p. Angino, E. E., Turner, M. D., and Zeller, E. J., 1962, Reconnaissance geology of Lower Taylor Valley, Victoria Land, Antarctica: Geol. Soc. America Bull. v. 73, p. 1553–1562.

Features illustrated.—Looking southwest along the Kukri Hills (center) toward the polar ice plateau (skyline). Taylor Valley, a typical dry valley, on the northwest side of the Kukri Hills extends for 32 kilometers to the terminus of Taylor Glacier. Ferrar Glacier on the southeast side of the hills is a typical valley glacier about 5 kilometers wide which flows 100 kilometers from the polar ice plateau. Small highland ice sheets in the Asgard Range (right, middle ground) nourish two expanded-foot glaciers, Commonwealth Glacier (to right) and Canada Glacier (center), on the valley floor. Much of the drainage in Taylor dry valley is to frozen Lake Fryxell (up valley from Commonwealth Glacier) and to frozen Lake Chad (up valley from Canada Glacier) because a glacial tongue from McMurdo Sound formerly occupied the valley.

Dust, blown downvalley, accentuates cracks in the sea ice on McMurdo Sound (foreground) and outlines individual floes of pack ice that are frozen into slightly younger sea ice (right foreground).

Metasedimentary and granitic rocks of probable late Precambrian and early Paleozoic age underlie the rugged mountainous terrain in the middle ground. Flat-lying strata of the Beacon Group and Ferrar Dolerite form most of the broad-topped mountains in the background.

Antarctica 17. Lower Taylor Glacier and Lake Bonney in Taylor Valley, Victoria Land

Area: Victoria Land.
Lat 77°45′ S.; long 162°30′ E.
Number of photographs: 1.
Photograph scale (foreground): About 1:40,000.
Focal length: 6 in.
Date flown: Nov. 7, 1959.
Map reference: U.S. Geol. Survey Taylor Glacier and Ross Island sheets, Antarctica, 1965, scale 1:250,000.
Geology reference: Angino, E. E., Turner, M. D., and Zeller, E. J., 1962, Reconnaissance geology of lower Taylor Valley, Victoria Land, Antarctica: Geol. Soc. America Bull., v. 73, p. 1553–1562. Gunn, B. M., and Warren, Guyon, 1962, geology of Victoria Land between the Mawson and Mulock Glaciers, Antarctica: New Zealand Geol. Survey Bull. 71, 157 p.

Features illustrated.—Looking west-southwest up Taylor Valley from near sea level to the polar ice plateau at 2,000–2,500 meters on skyline. Permanently ice-covered Lake Bonney (center) at terminus of Taylor Glacier is a saline-stratified lake with basal warm-water layers. Local glaciers flow into the dry valley from hanging tributary valleys in the Kukri Hills (left middle) and the Asgard Range (right). The Ferrar Glacier is to the left of the Kukri Hills. Metasedimentary and granitic rocks of probable late Precambrian and early Paleozoic age underlie Taylor Valley and adjacent mountains. Lamprophyre dikes cut granitic rocks in sharply defined fracture sets in the left foreground. The black splotches on the valley floor here and farther southwest are small basaltic cinder cones and flows that are younger than the oldest moraines. Taylor dry valley has a valley-in-valley form. The broad glacial valley is older than the basalt cones and flows, whereas an inner glacial valley, presently occupied in its upper part by the snout of the Taylor Glacier, is younger than the basalt. At the head of the lower Taylor Valley where the Taylor Glacier makes its last sharp abrupt bend, a black subhorizontal dolerite sill cuts the steep granitic valley sides. Upvalley from this area, most of the exposed rocks are flat-lying sandstones and arkoses of the Beacon Group, here of Devonian to Permian age, that are cut by many dolerite sills of probable Jurassic age.

Antarctica 18. Commonwealth Glacier, an expanded-foot glacier, Taylor Valley, Victoria Land

Area: Victoria Land.
Lat 77°35′ S.; long 163°15′ E.
Number of photographs: 1.
Photograph scale (foreground): About 1:15,000.
Focal length: 6 in.
Date flown: Jan. 1, 1958.
Map reference: U.S. Geol. Survey Ross Island sheet, Antarctica, 1965, scale 1:250,000.
Geology reference: Angino, E. E., Turner, M. D., and Zeller, E. J., 1962, Reconnaissance geology of Lower Taylor Valley, Victoria Land, Antarctica: Geol. Soc. America Bull. 73, p. 1553–1562. Gunn, B. M., and Warren, Guyon, 1962, Geology of Victoria Land between the Mawson and Mulock Glaciers, Antarctica: New Zealand Geol. Survey Bull. 71, 157 p.

Features illustrated.—Looking northwest across Taylor Valley to the terminus of Commonwealth Glacier which is fed by a local ice sheet in the eastern foothills (midground) of the Asgard Range. Beyond are the Ross Sea (upper right) and peaks of the Prince Albert Mountains (background). Commonwealth Glacier is an expanded-foot glacier with vertical terminal walls about 10 meters high. The relations of the faintly visible concentric layers and of the radial extension joints, which are crevasses deeply etched by ablation and by ephemeral melt water, to the curvature of the terminus imply a dynamic state of at least approximate equilibrium. The absence of excessive morainal debris at the terminus suggests growth rather than recession. However, growth may be only slight because the distributary melt-water channels are apparently well adjusted to the present position of the ice front. Drift, with polygonal patterned surface, that mantles the Taylor Valley floor is derived from a main-valley glacier that flowed upvalley from McMurdo Sound, less than 1 mile to the right; hence drainage on the valley floor is upvalley. Lateral moraines related to this upvalley glaciation, are visible on the valley side. Metasedimentary and granitic rocks of probable late Precambrian and early Paleozoic age are exposed on the valley side.

Antarctica 19. Onyx River and iced-covered Lake Vanda, Wright Valley, Victoria Land

Area: Victoria Land.
Lat 77°30′ S.; long 162° E.
Number of photographs: 1.
Photograph scale (foreground): About 1:40,000.
Focal length: 6 in.
Date flown: Nov. 7, 1959.
Map reference: U.S. Geol. Survey Ross Island and Taylor Glacier sheets, Antarctica, 1965 scale 1: 250,000.
Geology reference: McKelvey B. C., and Webb, P. N., 1962, Geology of Wright Valley, pt. 3 of Geological investigations in southern Victoria Land, Antarctica: New Zealand Jour. Geology and Geophysics, v. 5, no. 1, p. 143–162. Gunn, B. M., and Warren, Guyon, 1962, Geology of Victoria Land between the Mawson and Mulock Glaciers, Antarctica: New Zealand Geol. Survey Bull. 71, 157 p.

Features illustrated.—Looking southwest up Wright Valley from near sea level to the polar ice plateau at 2,000–2,500 meters on skyline. The ephemeral Onyx River drains south 35 kilometers up the dry valley to permanently ice-covered Lake Vanda (upper center). In center foreground the river flows through a recessional moraine of south-flowing Wright Lower Glacier that is beneath the camera. The Asgard Range (left) is the source of several local glaciers that terminate in Wright dry valley. These glaciers have characteristic steep-walled snouts. Gneiss and granodiorite of early Paleozoic age cut by lamprophyre dikes (about parallel to trend of valley) underlie Wright Valley. The terminus of Wright Upper Glacier rests on a structural bench underlain by a thick resistant sill of Ferrar Dolerite of Jurassic age. This sill is at the unconformity between the crystalline rocks and the overlying Beacon Group, here of Devonian and Permian age.

Antarctica 20. Moraines and patterned ground near Bull Pass, Wright Valley, Victoria Land

Area: Victoria Land.
Lat 77°30′ S.; long 162° E.
Number of photographs: 1.
Photograph scale (foreground): About 1:10,000.
Focal length: 6 in.
Date flown: Jan. 1, 1956.
Map reference: U.S. Geol. Survey Taylor Glacier sheet, Antarctica, 1965, scale 1:250,000.
Geology reference: McKelvey, B. C., and Webb, P. N., 1962, Geology of Wright Valley, pt. 3 of Geological investigations in southern Victoria Land, Antarctica: New Zealand Jour. Geology and Geophysics, v. 5, no. 1, p. 143-163.

Features illustrated.—Looking north from Wright Valley into the Olympus Range. The broad valley in center and left background is Bull Pass which hangs nearly 300 meters above the floor of Wright Valley. Bull Pass contains morainal debris, small frozen lakes, and several kames where two streams debouch into the valley from the east (right). The streaked west (left) slope of the pass suggests solifluction. The ephemeral Onyx River (foreground) on the Wright Valley floor flows west (left) up valley. An alluvial fan is being built below the mouth of the pass. Polygonal ground is especially visible in moist alluvium (right foreground). The valley wall is composed of granitic rocks of probable early Paleozoic age, which are cut by steeply dipping lamprophyre dikes, joints, and small faults that are differentially etched by erosion. The ragged dark-gray edge at the lip of Bull Pass is a dolerite sill of Jurassic age that cuts the granitic rock (light gray). The full thickness of the sill can be seen to the right.

Antarctica 21. Floating tongue of Campbell Glacier in Terra Nova Bay, Victoria Land

Area: Victoria Land.
Lat 74°30′ S.; long 165° E.
Number of photographs: 1.
Photograph scale (foreground): About 1:40,000.
Focal length: 6 in.
Date flown: Oct. 11, 1960.
Map reference: U.S. Geol. Survey Mount Melbourne sheet, Antarctica, 1968, scale 1:250,000.
Geology reference: Rieher, J. F., 1964, Outline of the geology between Mawson and Priestly Glaciers, Victoria Land, in Adie, R. J., ed., Antarctic geology: New York, John Wiley and Sons, p. 265–275.

Features illustrated.—Looking west across Terra Nova Bay to the 20-kilometer-long floating tongue of Campbell Glacier surrounded by 1-year-old sea ice. Flat-lying basalt flows and dolerite sills of probable Jurassic age form the plateau of Mount Nansen (in background) in front of which lies Priestley Glacier that extends from right skyline downward and to left across the photograph. Basalt flows and tuffs of Cenozoic age underlie most of the low-lying hills in the middle ground.

Antarctica 22. Priestley Glacier and polar ice plateau near Terra Nova Bay, Victoria Land

Area: Victoria Land.
Lat 74°30′ S.; long 163°30′ E.
Number of photographs: 1.
Photograph scale (foreground): About 1:45,000.
Focal length: 6 in.
Date flown: Dec. 6, 1961.
Map reference: U.S. Geol. Survey Mount Melbourne sheet, Antarctica, 1968, scale 1:250,000.
Geology reference: Rieher, J. F., 1964, Outline of the geology between Mawson and Priestley Glaciers, Victoria Land, in Adie, R. J. ed., Antarctic geology: New York, John Wiley and Sons, p. 265–275.

Features illustrated.—Looking south across edge of a small highland ice sheet to Priestley Glacier. Terra Nova Bay and Ross Sea are in upper left. Windablation moats (as much as 30 meters deep) surround small nunataks in left foreground. Basalt flows and tuffs of Cenozoic age underlie the foothills on either side of Priestley Glacier. The plateau in the right background, Mount Nansen (2,700 meters high), is underlain by about 1,200 meters of flat-lying basalt flows, interbedded sandstone, and dolerite sills of probable Jurassic age. Granitic rock of probable early Paleozoic age makes up the foothills below the scarp. The polar ice plateau, at an altitude of about 1,800 meters, lies beyond Mount Nansen on the right skyline.

Antarctica 23. Aretes, matterhorns, and U-shaped valleys near Trafalgar Glacier, Admiralty Mountains, northern Victoria Land

Area: Admiralty Mountains.
Lat 73°30′ S.; long 168°15′ E.
Number of photographs: 1.
Photograph scale (foreground): about 1:30,000.
Focal length: 6 in.
Date flown: Nov. 4, 1960.
Map reference: U.S. Geol. Survey Northern Victoria Land, Antarctica Sketch Map, 1968, scale 1:500,000. Am. Geog. Soc., Antarctica, 1965, scale 1:5,000,000.
Geology reference: Harrington, H. J., Wood, B. L., McKellar, I. C., and Lensen, G. J., 1967, Topography and geology of the Cape Hallet district, Victoria Land, Antarctica: New Zealand Geol. Survey Bull. 80, 99 p. Le Couteur, P. C., and Leitch, E. C., 1964, Preliminary report on the geology of an area southwest of upper Tucker Glacier, northern Victoria Land; *in* Adie, R. J., ed., Antarctic Geology: New York, John Wiley and Sons, p. 229–236.

Features illustrated.—Looking north-northeast across the Trafalgar (left and center) and Tucker Glaciers (middle) to the rugged Admiralty Mountains (background). The Ross Sea is behind the black pyramid of Mount Herschel, altitude 3,335 meters, on the upper right. Mount Minto is the highest peak (altitude 4,163 meters) just to left of center skyline. The presence of matterhorns, steep slopes, and U-shaped valleys indicates vigorous glacial erosion.

Granitic rock of Paleozoic age underlies the rough blocky rock surfaces in the center foreground. Low-grade metasedimentary slate and graywacke of the Robertson Bay Formation of probable late Precambian age underlie most of the rest of the terrain. The metasedimentary rocks are intensely folded about northwest-trending axes nearly parallel to the trend of the Tucker Glacier.

Antarctica 24. Glaciers of the Admiralty Mountains on edge of ice-covered Robertson Bay, northern Victoria Land

Area: Admiralty Mountains.
Lat 71°30′ S.; long 170° E.
Number of photographs: 1.
Photograph scale (foreground): About 1:50,000.
Focal length: 6 in.
Date flown: Nov. 2, 1961.
Map reference: U.S. Geol. Survey Northern Victoria Land, Antarctica Sketch Map, 1968, scale 1:500,000. Am. Geog. Soc., Antarctica, 1965, scale 1:5,000,000.
Geology reference: Harrington, H. J., Wood, B. L., McKellar, I. C., and Lensen, G. J., 1967, Topography and geology of the Cape Hallett district, Victoria Land, Antarctica: New Zealand Geol. Survey Bull. 80, 99 p. Rastall, R. H., and Priestley, R. E., 1921, The slate-graywacke formation of Robertson Bay: British Antarctic ("Terra Nova") Exped., 1910, Nat. History Dept., Geology, v. 1, no. 4, p. 121–128.

Features illustrated.—Looking south-southwest across Robertson Bay and the icebound shore of the Pacific Ocean to the Admiralty Mountains, which rise to an altitude of 4,000 meters. Cape Adare is just off the photograph to the left, and Cape Hallett is to the upper left (below skyline). U-shaped valleys 500–1,000 meters deep, aretes, and horns indicate vigorous erosion by valley glaciers in the mountains. The Dugdale Glacier with its jagged floating ice tongue is left of center, and the sinuous Ommanney Glacier is to the right. One-year-old sea ice (gray) covers Robertson Bay, and north-northwest-trending sastrugi (light-gray streaks) on the bay ice are parallel to the length of the bay.

Low-grade metasedimentary slate and graywacke of the Robertson Bay Formation of probable late Precambrian age underlie the mountains. These rocks are intensely folded about northwest-trending axes nearly parallel to the shoreline in the middle ground. Volcanic rocks of Cenozoic age underlie most of the mountain on the right end of the shoreline as well as Cape Hallett.

Bikini 1. Airukiiji Island and adjoining reefs, Bikini Atoll

Area: Airukiiji Island.
Lat 11°31′ N.; long 165°25′ E.
Number of photographs: 3.
Photograph scale: 1:5,000.
Focal length: 24 in.
Date flown: Unknown.
Map reference: Chart 2 in geology reference, scale 1:50,000.
Geology reference: Emery, K. O., Tracey, J. I., Jr., and Ladd, H.S., 1954, Geology of Bikini and nearby atolls: U.S. Geol. Survey Prof. Paper 260-A, p. 1–264. See pl. 15, fig. 2.

Features illustrated (set nos. Bikini 1 A–C in southwest corner of photographs. Photographs trimmed from 9- by 18-inch size).—The channeled seaward edge of the platform of Bikini Atoll is visible through several tens of feet of water near the south edges of photographs. The fringing reef at the breaker line has an irregular "combtooth" margin, unlike the reef on the lagoonward (north) side. The water of the lagoon is much quieter than the rough water of the open sea, even though whitecaps are present.

Waves have washed sand toward the lagoon in the pass between Airukiiji Island (photograph 1 B) and

Airukiraru Island (southwest quadrant photograph 1 A); the broad pass east of Airukiiji is Enyu Channel (photograph 1 C). A stand of coconut palms, identified by the stellate pattern and open canopy, contrasts with surrounding woods and brush covering most of the island.

Bikini 2. Storm-damaged coral reef, Enirik Island, Bikini Atoll

Area: Enirik Island.
Lat 11°30′ N.; long 165°20′ E.
Number of photographs: 4.
Photograph scale: 1:5,000.
Focal length: 24 in.
Date flown: Unknown.
Map reference: Plate 2 in geology reference.
Geology reference: Emery, K. O., Tracey, J. I., Jr., and Ladd, H. S., 1954, Geology of Bikini and nearby atolls, Part 1, Geology: U.S. Geol. Survey Prof. Paper 260-A, p. 1-264. See text figs. 8 and 9 and fig. 4 of pl. 13, taken from northwest quadrant of photograph 3.

Features illustrated (set nos. Bikini 2 A-D in southwest corner of photographs. Photographs trimmed from 9- by 18-inch size).—Enirik Island and adjoining reef, at southernmost point of Bikini Atoll. Southeast of island, the reef has long, narrow, subequal reentrants ("combtooth" pattern, type II-B-2, of Emery and others), but on southwest side the reef has large irregular reentrants (type II-B-1; photographs A and B). The large reentrants are the result of erosion by storm waves. Although area is on lee side of atoll in relation to prevailing trade winds (note wave pattern at sea and breaker pattern on reefs), reef is occasionally battered by severe storm waves from south. Blocks thrown up onto reef by storm waves are visible in southeast quadrant of photograph C.

Bolivia 1. Achocalla Mudflow, south of La Paz, Bolivia

Lat 16°33′ S.; long 68°07′ W.
Number of photographs: 4.
Photograph scale: 1:50,000.
Focal length: 6 in.
Date flown: May 28, 1956.
Map reference: Plate 2 in geology reference.
Geology reference: Dobrovolny, Ernest, 1962, Geología del valle de La Paz; Bolivia, Departamento Nacional de Geología, Bol. no. 3, p. 62-63. See lamina 2.

Features illustrated (set nos. Bolivia 1 A-D in southwest corner of photographs).—The Rio Mallasa heads in breaks of a high plain (the altiplano, west half photograph A) and flows east to south-flowing Rio La Paz (east half photograph C). The Achocalla Mudflow originated near head of Rio Mallasa, descended more than 600 meters in 10 kilometers to main valley where a bedrock spur deflected it south. Landslide topography, with closed depressions and ponds, persists (southwest quadrant photograph C). According to Dobrovolny, the mudflow, about 2.5 cubic kilometers of material, ponded Rio La Paz to a depth of at least 150 meters. This ponding flooded site of La Paz suburb Calacoto (prominent racetrack); deposits of Lake Calacoto reach a thickness of 45 meters. Lake apparently is younger than glacial drift which is 9,000 years old by radiocarbon dating; thus Achocalla Mudflow is probably of Recent age. The railroad grade descending from the altiplano in northwest quadrant of photograph B was abandoned in 1928 when it was destroyed by landslides.

Bolivia 2. Oriented lakes in the Beni Basin northeast of La Paz

Lat 14°45′ S.; long 66°00′ W.
Number of photographs: 4.
Photograph scale: 1:40,000 (verticals).
Focal length: 6 in.
Date flown: 1948.
Geology reference: Plafker, George, 1964, Oriented lakes and lineaments of northeastern Bolivia: Geol. Soc. America Bull., v. 75, p. 503-522.

Features illustrated (Bolivia 2 A is an oblique photograph, view east. Set nos. Bolivia 2 B-D in northwest corner of photographs).—Two of several hundred shallow lakes with shorelines oriented roughly northeast-southwest and northwest-southeast. Most lakes have no inlet or outlet. The lakes are in upper Cenozoic clastic sediments that overlie crystalline rocks of the Brazilian Shield. Lakeshores parallel structural trends in the basement, and Plafker infers that the lakes formed by subsidence of individual basement blocks. The lake near the northwest corner of photograph C is just above the center of photograph A and near the right edge of Plafker's figure 2. Photograph A shows other oriented lakes in the distance. The region is predominantly grassland; forest is largely confined to belts along streams and to fringes along much of the lakeshores.

Brazil 1. Pontal de Sernambetiba, a tombolo southwest of Rio de Janeiro

Lat 23°02′ S.; long 43°28′ W.
Number of photographs: 3.
Photograph scale: 1:20,000.
Focal length: 6 in.
Date flown: Nov. 29, 1964.
Map reference: See geology reference.
Geology reference: Brazil, Secretaria Geral de Agricultura, Indústria e Comércio, 1949, Mapa geológico do Distrito Federal, scale 1:87,000.

Features illustrated (set nos. Brazil 1 A-C in southwest corner of photographs).—A cliffed bedrock hill of granite and "lenticular gneiss" (near center of photograph B) is tied to the mainland by a sandbar or tombolo. The coast is mainly wave built; a notation on the map indicates that near the tombolo the shore is advancing at the rate of 1 meter per year. Patterns in the water show how waves are refracted by the former island. These waves caused sand to move in behind the island and build the sand bar that ties it to the shore. Another steep-sided hill of granite gneiss, near the west edge of photograph B, rises above the coastal plain; a third granite gneiss hill (Peças, in the southwest quadrant of photograph A) is still an offshore island. East of the tombolo, a lagoon and tidal marsh are behind the beach, which here becomes a bar.

Chile 1. Artesian conditions at Pica oasis, Atacama Desert

Area: Province of Tarapacá.
Lat 20°30′ S.; long 69°20′ W.
Number of photographs: 4.
Photograph scale: 1:60,000.
Focal length: 6 in.
Date flown: Apr. 7, 1955.
Map reference: Pica and Matilla sheets in geology reference, scale 1:50,000. U.S. Air Force World Aeronautical Chart, Point Angamos sheet (1258), scale 1:1,000,000.
Geology reference: Galli Olivier, Carlos, and Dingman, R. J., 1962, Cuadrangulos Pica, Alca, Matilla y Chacarilla, con un estudio sobre los recursos de agua subterránea, Provincia de Tarapacá: Chile, Instituto de Investigaciones Geológicas, 125 p. Dingman, R. J., and Galli O., Carlos, 1965, Geology and ground-water resources of the Pica area, Tarapacá Province, Chile: U.S. Geol. Survey Bull. 1189. See figs. 22 and 23.

Features illustrated (*set nos. Chile 1 A–D in southeast corner of photographs*).—East half of area is a west-facing dip slope, partly dune covered, on an ignimbrite member of Altos de Pica Formation. Ridge west of Pica oasis (southeast quadrant of photograph C) marks upthrown side of a north-south fault that brings impermeable Jurassic rocks (exposed near center of photograph D) against an aquifer in basal Altos de Pica beds. Ground water escapes upward through fractures to form springs that irrigate the fruit groves of Pica. The several oases from Pica to Puquio de Núñez (south center of photograph A) are fed by infiltration galleries that recover seepage water from Pica irrigation. A flowing well at Salto Chico (dry falls that breach ignimbrite southeast of Pica) yields water for irrigation in the quebrada (arroyo) and for the city of Iquique, some 75 miles away on the coast. A pipeline runs northwest beside the road in northwest quadrant of photograph A. Stereoscopic coverage of Puquio de Núñez is provided by Chile 2 B.

Chile 2. Mudflow fan of Quebrada Chacarilla, Atacama Desert

Area: Province of Tarapacá.
Lat 20°40′ S.; long 69°20′ W.
Number of photographs: 2.
Photograph scale: 1:60,000.
Focal length: 6 in.
Date flown: Apr. 7, 1955.
Map reference: Matilla sheet in geology reference, scale 1:50,000. U.S. Air Force World Aeronautical Chart, Point Angamos sheet (1258), scale 1:1,000,000.
Geology reference: Galli Olivier, Carlos, and Dingman, R. J., 1962, Cuadrangulos Pica, Alca, Matilla y Chacarilla, con un estudio sobre los recursos de agua subterránea, Provincia de Tarapacá: Chile, Instituto de Investigaciones Geológicas, 125 p. Dingman, R. J., and Galli O., Carlos, 1965, Geology and ground-water resources of the Pica Area, Tarapacá Province, Chile: U.S. Geol. Survey Bull. 1189, 113 p.

Features illustrated (*set nos. Chile 2 A, B in southeast corner of photographs*).—Quebrada (arroyo) Chacarilla, which enters area of photograph A near southeast corner, has built a broad fan marked by complex patterns of braided channels. The most recent flow, along north edge of fan, largely effaced the fan of smaller Quebrada Puquio Núñez (northwest quadrant of photograph A). According to Dingman and Galli O., the fans are built by mudflows that occur at intervals of several years; the conspicuous channels in the mudflow deposits are carved as the flow is decreasing. Above its fan, Quebrada Chacarilla carries water at night and in the morning and dries up each afternoon (Dingman, written commun., 1964). The water is too salty—2,423 ppm (parts per million) chloride, 5,531 ppm total dissolved solids—for domestic or irrigation use. A small oasis, Puquio de Núñez (dark patch near center of photograph B), gets its water from an infiltration gallery. For stereoscopic coverage of the northern part of photograph B, see Chile 1A.

Chile 3. Open pit copper mine at Chuquicamata, Chile

Area: Province of Antofagasta.
Lat 22°20′ S.; long 68°55′ W.
Number of photographs: 2.
Photograph scale: 1:55,000.
Focal length: 6 in.
Date flown: Apr. 18, 1961.
Map reference: U.S. Air Force World Aeronautical Chart, Point Angamos sheet (1258), scale 1:1,000,000.
Geology reference: Renzetti, B. L., 1957, Geology and petrogenesis at Chuquicamata, Chile: Dissert. Abs., v. 17, no. 10, p. 2249.

Features illustrated (*set nos. Chile 3 A, B in southeast corner of photographs*).—The copper mine at Chuquicamata, in the Chilean desert at an altitude of about 9,000 feet, is an open pit about 2 miles long with terraced slopes. The great dumps of waste as well as the size of the pit reflect the large amount of material that has been mined. Vegetation is completely lacking, the result of an extremely arid climate that doubtless accounts for the unique mineralogy of the deposit; according to Renzetti, the deposit is generally similar to other porphyry copper deposits, except that much of the copper is in the form of hydrous sulfates.

Chile 4. Volcanoes in the high Andes on the Chile-Bolivia border

Area: Andes mountains.
Lat 22°50′ S.; long 67°52′ W.
Number of photographs: 3.
Photograph scale: 1:45,000.
Focal length: 6 in.
Date flown: Apr. 27, 1961.
Map reference: U.S. Air Force World Aeronautical Chart, Point Angamos sheet (1258), scale 1:1,000,000.
Geology reference: Chile, Instituto de Investigaciones Geologicas, 1960, Mapa Geológica de Chile, scale 1:1,000,000.

Features illustrated (set nos. Chile 4 A–C in southeast corner of photographs).—Licancáhur Volcano (northwest quadrant photograph B), a symmetrical cone with summit crater about 800 feet in diameter, has radial grooves (avalanche scars?) on steep upper slopes and radiating lava tongues; several have curved transverse ridges and natural levees on lower slopes. The lavas were viscous; the tongues have high steep flanks and fronts. Southeast of Licancábur, a second cone, with a summit caldera more than a mile in longer diameter, has lava tongues with subdued forms that imply an age greater than that of Licancábur. Though both peaks show autumn snows that indicate their high altitude, they lack cirques such as occur at high altitudes to the north (see Ecuador 2) and south. This fact suggests that the climate was dry in the Pleistocene as it is today. Both volcanoes stand on an older surface of ignimbrite (southwest quadrant of photograph A) at altitudes above 12,000 feet.

Chile 5. Lavas controlled by stream valleys

Area: Province of Antofagasta.
Lat 22°45′ S.; long 68°05′ W.
Number of photographs: 3.
Photograph scale: 1:60,000.
Focal length: 6 in.
Date flown: Apr. 7, 1961.
Map reference: Maps in geology references.
Geology reference: Dingman, R. J., 1967, Geology and groundwater resources of the northern part of the Salar de Atacama, Antofagasta Province, Chile: U.S. Geol. Survey Bull. 1219, 49 p. Dingman, R. J., 1968, Carta geológica de Chile, Cuadrangulo San Pedro, Provincia de Antofagasta: Chile, Instituto de Investigaciones Geológicas.

Features illustrated (set nos. Chile 5 A–C in southeast corner of photographs).—The west slope of the Andes is here a dip slope on a Pliocene welded tuff (southwest quadrant of photograph A). Canyons carved in this surface determined the locations of two basalt tongues, which descended westward from the high mountains (outside area shown in photographs). The mechanism of this control is suggested by the westernmost tongue, which is in part a collapsed lava tube. The basalt, in turn, has partly controlled postbasalt erosion. The basalt was viscous and has an aa surface. North of the flows are several partly exposed ring dikes that surround the base of an old volcano, now largely eroded away.

Chile 6. Thrusting in near-surface rocks near San Pedro de Atacama

Area: Province of Antofagasta.
Lat 22°45′ S.; long 68°20′ W.
Number of photographs: 3.
Photograph scale: 1:60,000.
Focal length: 6 in.
Date flown: Apr. 9, 1961.
Map reference: Plate in pocket of second geology reference.
Geology reference: Dingman, R. J., 1963, Reversal of throw along a line of low-angle thrust faulting near San Pedro de Atacama, Chile: U.S. Geol. Survey Prof. Paper 450-E, p. E25–E27. Dingman, R. J., 1963, Carta geológica de Chile, Cuadrangulo Tulor, Provincia de Antofagasta: Chile, Instituto de Investigaciones Geológicas, Carta no. 11, scale 1:50,000.

Features illustrated (set nos. Chile 6 A–C in southeast corner of photographs).—Thrust faulting formed a line of hills that extends southwest from the northeast corner of photograph B across a southeast-sloping piedmont. Welded tuffs of late Tertiary age (light tone) were faulted when underlying Tertiary rocks (northwest quadrant of photograph B) glided toward basin that lies to southeast (see Chile 7, which adjoins this set on south). On Photograph A the fault is an underthrust that extends along northwest side of ridge; here tuff in the static block overrode rocks of same and somewhat younger age. In next hill to northeast (south of center of southeast quadrant of photograph C), fault is an overthrust that crops out near southeast side of ridge; here Quaternary mudflows (dark tone) cap tuff in the active plate. Bajadas, built chiefly by mudflows, show braided stream patterns.

Chile 7. Salt-lubricated folding and doming in the Atacama Desert

Area: Province of Antofagasta.
Lat 22°54′ S.; long 68°20′ W.
Number of photographs: 3.
Photograph scale: 1:60,000.
Focal length: 6 in.
Date flown: Apr. 9, 1961.
Map reference: Plate in pocket of second geology reference.
Geology reference: Dingman, R. J., 1962, Tertiary salt domes near San Pedro de Atacama, Chile: U.S. Geol. Survey Prof. Prof. Paper 450–D, p. D92–D94. Dingman, R. J., 1963, Carta geológica de Chile, Cuadrangulo Tulor, Provincia de Antofagasta: Chile, Instituto de Investigaciones Geológicas, Carta no. 11, scale 1:50,000.

Features illustrated (set nos. Chile 7 A–C in southeast corner of photographs).—In the Cerros de la Sal (most of photograph B) both anticlinal and synclinal ridges and valleys are well illustrated. The rocks are continental arid-basin deposits of early Tertiary age, chiefly fine-grained clastic rocks with many salt and gypsum beds. Dingman attributes the complex structures to incompetent folding under compression, as rocks lubricated by the evaporites glided toward the axis of the basin from both sides (Chile 6 adjoins this set on north). Dingman interprets the dark ridge (resembling a railroad embankment) across valley about 1.5 inches northeast of center of photograph B as eolian sand; similar dark-toned sand occurs on the lee (southeast) sides of ridges elsewhere. Figure 147.2 in the first geology reference is an annotated copy of most of photograph B.

Chile 8. Fan diversion of drainage

Area: Province of Antofagasta.
Lat 23°10′ S.; long 70°08′ W.
Number of photographs: 2.
Photograph scale: 1:60,000.
Focal length: 6 in.
Date flown: Apr. 14, 1955.
Map reference: U.S. Air Force World Aeronautical Chart, Point Angamos sheet (1258), scale 1:1,000,000.
Geology reference: Chile, Instituto de Investigaciones Geológicas, 1960, Mapa Geológica de Chile, scale 1:1,000,000.

Features illustrated (set nos. Chile 8 A, B in southeast corner of photographs).—A precipitous fault scarp trending north-northeast marks the straight west side of a narrow fault valley (west half of photograph A). The main stream, flowing south-southwest in the fault valley, is forced to detour around two fans built by streams that drain small valleys in the mountains to the west. Elsewhere the scarp is fronted by a bajada built by small streams that head on the scarp. Where a fan built by a stream from the east is opposed to the bajada, the main stream is confined to a narrow, straight channel. Upstream (north half of photograph B) the valley widens, and the main stream forms a wide belt of braided channels. The mountains west of the fault are of Mesozoic granite; east of the valley they are of Jurassic volcanic and sedimentary rocks.

China 1. Dissected loess plain on lee side of Gobi Desert

Area: Shansi Province.
Lat approx 38° N.; long approx 112° E.
Number of photographs: 3.
Photograph scale: 1:30,000 (verticals).
Focal length: 6 in.
Date flown: Mar. 27, 1947.
Map reference: Army Map Service series 1301, sheet NJ49, Yang-Chu sheet, scale 1:1,000,000.

Features illustrated (China 1 A is oblique view, south-southwest. China 1 B, C are vertical, set nos. in north corners).—Thick loess blankets this region where rainfall is sufficient to support vegetation that can catch and hold dust deflated from the Gobi Desert to the west. The loess is deeply dissected; the mud load that gives the Yellow River its name testifies to the easy erodibility of this material. Most gullies are dendritic in pattern (contrast with China 2). Every hill and gully slope is terraced for cultivation. Long, narrow, cultivated fields of a flat tableland in photograph B extend approximately north-south.

China 2. Gully erosion in loess, promoted by works of man

Area: Shansi Province.
Lat approx 39° N.; long approx 114° E.
Number of photographs: 2.
Photograph scale: 1:50,000.
Focal length: 6 in.
Date flown: 1943.
Map reference: Army Map Service, series 1301, sheet NJ 50, Pei Ping sheet, scale 1:1,000,000.

Features illustrated (set nos. China 2 A, B in west corner of photographs).—Area shown is in western China on the lee (east) side of the Gobi Desert. In mountainous areas, including much of the north-northeast half of the photographs, loess is thin or absent and valleys have a dendritic pattern, but in more level areas, including most of the south-southeast half, thick loess (see China 1) forms dissected tablelands on which many gullies are rectilinear. Near the east edge of the area of stereoscopic coverage, rectilinear gullies form two sets, which drain south and west, respectively. Many of the rectilinear gullies, as near the south corner of photograph A and south of the center of photograph B, are parallel to or collinear with cultivation patterns that reflect property boundaries. This relation arises because the gullies originated as washed-out roads and washed-out cultivation furrows.

Ecuador 1. Lava flow on flanks of Antisana Volcano

Area: Pichincha.
Lat 0°26′ S.; long 78°16′ W.
Number of photographs: 3.
Photograph scale: 1:60,000.
Focal length: 6 in.
Date flown: Mar. 7, 1963.
Map reference: Army Map Service, series 1301, sheet SA17, Quito sheet, scale 1:1,000,000.

Features illustrated (set nos. Ecuador 1 A–C in southeast corner of photographs).—Lava emerged from two vents (near northeast corner of photograph C) on the side of a deep valley on the lower slopes of Antisana Volcano. Most of the lava flowed downvalley, but a little flowed a short distance upvalley, where it now impounds a lake. The main flow has conspicuous levees, where it is confined within the valley and downslope where it emerges onto the adjacent plain. There the flow bifurcates into two steep-sided tongues with bulbous protrusions on their flanks. Lava cascades descend from the plain into a deep canyon, where the lava has dammed two more lakes.

Ecuador 2. Mount Cotopaxi, a glacier-clad equatorial volcano

Area: Pichincha.
Lat 0°41′ S.; long 78°27′ W.
Number of photographs: 3.
Photograph scale: 1:30,000.
Focal length: 6 in.
Date flown: June 22, 1963.
Map reference: Army Map Service, series 1301, sheet SA17, Quito sheet, scale 1:1,000,000.
Geology reference: Whymper, Edward, 1892, Travels amongst the great Andes of the equator: London, John Murray, and New York, Charles Scribner's Sons, 456 p. See p. 123 and 136–155.

Features illustrated (set nos. Ecuador 2 A–C in southeast corner of photographs).—The great bulk of this nearly symmetrical volcano, which rises to an altitude of 19,344 feet, dwarfs its round summit crater. Despite its proximity to the equator, glaciers (severely crevassed) cover most slopes above 16,000 feet. In places, the limit of glacier ice is difficult to determine because snow whitens ground to well below glacier limit. According to Whymper, snow falls nightly and melts daily under the tropical sun. Snow on the rim of an inner crater is apparently thick, suggesting that the volcano is not continuously active as in Whymper's day. Catastrophic eruptions have occurred. In 1877, ash from Cotopaxi turned day into night at Quito, 32 miles away; ash fell on ships 200 miles away, and lava pouring onto glaciers initiated destructive mudflows. Below snowline, drainage is radial.

Equador 3. Cirques in jointed metamorphic rocks east of Gualaceo

Area: Azuay.
Lat 2°55′ S.; long 78°45′ W.
Number of photographs: 2.
Photograph scale: 1:40,000.
Focal length: 6 in.
Date flown: June 22, 1963.
Map reference: Army Map Service, series 1301, sheet SA17, Quito sheet, scale 1:1,000,000.

Features illustrated (set nos. Ecuador 3 A, B in southeast corner of photographs).—Rock basins containing ponds are evidently cirques with tarns. Snow is lacking; snowline must have been lower when the cirques were formed. The absence of snow even in midwinter, in an area of appreciable rainfall, indicates that the lower snowline was due at least partly to lower temperatures rather than heavier precipitation. Cooling at this equatorial latitude suggests that Pleistocene cooling was worldwide. The jagged forms of the cliffs, ridges, and valleys are controlled chiefly by strong foliation and joint patterns in bedrock, perhaps emphasized by frost action. Rock is widely exposed; very little regolith, either residual or transported, is present.

Guatamala 1. Radial drainage an Agua Volcano

Area: Sacatepéquez.
Lat 14°28′ N.; long 90°45′ W.
Number of photographs: 2.
Photograph scale: 1:50,000.
Focal length: 6 in.
Date flown: Jan. 29, 1954.
Map reference: Coast and Geodetic Survey, series ONC K–25, scale 1:1,000,000.
Geology reference: Williams, Howel, 1960, Volcanic history of the Guatemalan Highlands: California Univ. Pubs. Geol. Sci., v. 38, no. 1, p. 47–48.

Features illustrated (set nos. Guatemala 1 A, B in southwest corner of photographs).—A composite volcano, one of many in the Guatemalan Highlands. Crater rim is complete, except on north-northeast side. Height of cone (about 7,000 ft above base) approaches that of Cotopaxi (Ecuador 2), but because altitude (12,336 ft) is less, snow is lacking, and upper part of cone is forested. According to Williams, there is no authentic record of eruptions from Agua in historic times. Mudflows from its summit crater destroyed the first capital of Guatemala, Ciudad Vieja (near northwest corner photograph B), in 1541. These mudflows have been attributed to an eruption, but more likely were caused by sudden discharge of a lake when part of the crater rim collapsed during heavy rains. All the lavas and pyroclastic ejecta of Agua are hypersthene-augite andesites.

Iran 1. Wind transportation of dust: Dust devils

Lat 33°48′ N.; long 58°24′ E.
Number of photographs: 2.
Photograph scale: 1:55,000.
Focal length: 6 in.
Date flown: Aug. 7, 1956.
Map reference: Coast and Geodetic Survey, series ONC G–5, scale 1:1,000,000.

Features illustrated (set nos. Iran 1 A, B in northeast corner of photographs).—The sun is blazing from a cloudless sky on the dark-toned surface of a cultivated plain where two light-gray cones with indistinct boundaries rise almost vertically from the surface. These cones cast dark-gray shadows and are evidently "dust devils," vortexes of air that rise convectively from the hot ground and are revealed by the dust they carry upward. Dust haze obscures the pattern of the fields in the vicinity of the dust devils. A third vortex, indistinct on photograph A, is apparently just forming; a fourth appears near east edge of photograph B outside area of stereoscopic coverage. The dust devils moved southwest after photograph A was taken and before photograph B was taken. This movement shows that the dust is actually being transported across the plain, not merely being redistributed. The irrigated area in the northeast corner of photograph B is outside Sarāyān (Robert S. Jones, oral commun., 1965.)

Iran 2. Streaks inferred to be tracks of dust devils

Lat 30°52′ N.; long 58°38′ E.
Number of photographs: 1.
Photograph scale: 1:55,000.
Focal length: 6 in.
Date flown: Aug. 25, 1956.
Map reference: Coast and Geodetic Survey, series ONC, H-7, scale 1:1,000,000.

Features illustrated (set no. Iran 2 in northeast corner of photograph).—An aggraded alluvial desert plain is marked by a pattern of faint lines. According to Robert S. Jones (oral commun., 1965), these are tracks left where dust devils have moved across the surface. The alluvial plain, a gently sloping bajada on the flank of a bolson, is seamed with a pattern of roughly parallel braided channels draining southwest. The supposed tracks form an intersecting pattern of straight to gently curving streaks, trending generally from northwest to southeast, roughly at right angles to the channels. The streaks are darker in tone than the background, possibly because the removal of light-colored fines from the surface leaves a residue of coarse material that is darker in tone.

Iran 3. Wind-scoured troughs and yardangs of the Shahr-e Lūt

Lat 30°50′ N.; long 58°15′ E.
Number of photographs: 2.
Photograph scale: 1:55,000.
Focal length: 6 in.
Date flown: Aug. 22, 1956.
Map reference: Coast and Geodetic Survey, series ONC, H-7, scale 1:1,000,000.

Features illustrated (set nos. Iran 3 A, B in northeast corner of photographs).—Carving of troughs, evidently by wind erosion and deflation, has left intervening residual ridges (yardangs). The long, narrow, steep-sided ridges are a few hundred to 1,500 feet wide, a few feet to more than 100 feet high, and 0.1 mile to several miles long; they are spaced a few hundred to nearly 2,000 feet apart. They are parallel, have blunt noses, and tail off to the south-southeast; clearly, the effective winds are from the north-northwest. The troughs are carved in fine-grained material (lake beds?) accumulated in the central part of this broad desert basin. This area of ridges and troughs is sometimes known as the Shahr-e Lūt (City of the Desert) because the troughs bear a fancied resemblance to streets between rows of mud-brick houses. The floors of the troughs, between the yardang ridges, are uneven, form closed depressions, and are dark in color; they are probably floored with lag deposits (sand?). Iran 4 adjoins this set on the east.

Iran 4. Possible doming of the Shahr-e Lūt basin

Lat 30°50′ N.; long 58°15′ E.
Number of photographs: 2.
Photograph scale: 1:55,000.
Focal length: 6 in.
Date flown: Aug. 22, 1956.
Map reference: Coast and Geodetic Survey, series ONC, H-7, scale 1:1,000,000.

Features illustrated (set nos. Iran 4 A, B in northeast corner of photographs).—Area shown is at northeast edge of the Shahr-e Lūt (see Iran 3, adjoining this set on west). A stream from the north that approaches the Shahr-e Lūt northwest of the photographs is diverted southeast along the margin of the yardang area and finally ends in the north half of these photographs (limits reached by water the last time the stream flowed are shown by white saline incrustation). Stream was ponded repeatedly by low residual ridges at edge of the Shahr-e Lūt. This ponding filled each flat up to the level at which water could spill over into the next one. The manner in which the stream detours around the margin of the Shahr-e Lūt, without extending far along the deep troughs toward the center of the bolson, suggests that the (lake?) beds from which the yardangs were carved have been tilted after deposition, perhaps by isostatic doming analogous to that inferred in the basin of Lake Bonneville.

Iran 5. Khanats, the underground water-collecting galleries of Iran

Lat 30°54′ N.; long 55°18′ E.
Number of photographs: 2.
Photograph scale: 1:55,000.
Focal length: 6 in.
Date flown: July 6, 1956.
Map reference: Coast and Geodetic Survey, series ONC, H-7, scale 1:1,000,000.

Features illustrated (set nos. Iran 5 A, B in northeast corner of photographs).—The rows of dots extending west across southwest quadrant of photograph B mark the courses of khanats, underground infiltration galleries that collect ground water moving northeast through the alluvial deposits and divert it to flow obliquely to the fan's surface to the town of Anar (southeast quadrant). The khanat tunnels are driven from shafts; the spoil from a shaft and from the tunnel excavated in both directions from its bottom is dumped around the shaft head, and these piles of waste are the dots seen on the photographs. Such tunnels are subject to caving and require cleaning out from time to time. This enlarges the piles of spoil around the shafts. Eventually the time comes when it is considered better to drive a new khanat than to try to reopen an old one; this accounts for the parallel rows of dots. At least seven lines of dots can be seen on the photographs.

Iran 6. Dah Kuh salt plug and salt glacier

Lat 27°55′ N.; long 54°25′ E.
Number of photographs: 3.
Photograph scale: 1:55,000.
Focal length: 6 in.
Date flown: May 27, 1956.
Map reference: Army Map Service, series K501, sheet G-40 A, Lar sheet, scale 1:250,000.
Geology reference: Harrison, J. V., 1930, The geology of some salt-plugs in Laristan (southern Persia): Geol. Soc. London Quart. Jour., v. 86, no. 344, p. 463–520. See p. 492; pl. 53, fig. 1; and location map, p. 476.

Features illustrated (set nos. Iran 6 A–C in northeast corner of photographs).—Folded Tertiary sedimentary rocks in the Iranian desert form strike ridges that trend west-northwest and that are separated by valleys containing alluvial deposits. Harrison's Dah Kuh salt plug has been extruded at the crest of an anticlinal mountain. In this arid climate, the salts, chiefly halite and gypsum, not only survive in outcrop but form the highest summit in the vicinity. The salts have flowed in both directions along an adjacent valley. The resulting salt tongues, the longer one about 3 miles long, have rough surfaces and steep sides and resemble glaciers or tongues of viscous lava. The area is poorly known, and the features shown on Harrison's maps cannot be positively tied to those shown on the Army Map Service map; the village in the southwest quadrant of photograph B may be Dehkūyeh (Dehkūh of the Army Map Service map) and the salt plug the hill Kūh-i-Ninak.

Iran 7. Kūh-i-Gach salt plug and salt glacier

Lat 27°35′ N.; Long 54°25′ E.
Number of photographs: 3.
Photograph scale: 1:55,000.
Focal length: 6 in.
Date flown: May 28, 1956.
Map reference: Army Map Service, series K501, sheet G-40 A, Lar sheet, scale 1:250,000.
Geology reference: Harrison, J. V., 1930, The geology of some salt-plugs in Laristan (southern Persia). Geol. Soc. London Quart. Jour., v. 86, no. 344, p. 463–520. See p. 485 and pl. 56.

Features illustrated (set nos. Iran 7 A–C in northeast corner of photographs).—The Kūh-i-Gach salt plug has punched its way through to the surface, where it forms a hill more than 1,000 feet high (north half of photograph B). The salt and gypsum have flowed downhill toward the south; the resulting tongue-shaped body, more than 3 miles long, resembles a glacier or a flow of viscous lava, with arcuate transverse ridges separated by crevasselike gullies and with steep sides and front. Though the surface is rough, the tongue as a whole slopes gently southward from the base of the steeper slope of the dome that fed it. A stream is diverted around the terminus of the tongue. The village west of the tongue near center of photograph C is Nīhmeh; that southeast of the terminus in the southwest quadrant of photograph A is Karmusteh. The terminus of another salt glacier, Kuh-i-Siah Taq, lies 4 miles east of Karmusteh (southeast corner of photograph A).

Japan 1. Suggested analog of Moon's sinuous rills on Asama Volcano

Area: Honshū Island.
Lat 36°25′ N.; long 138°32′ E.
Number of photographs: 3.
Photograph scale: 1:40,000.
Focal length: 6 in.
Date flown: Nov. 6, 1947.
Map reference: Army Map Service, series L774, sheet 5856 III, Karuizawa sheet, scale 1:50,000.
Geology reference: Aramaki, Shigeo, 1963, Geology of Asama Volcano: Tokyo Univ. Fac. Sci. Jour., sec. 2, v. 14, pt. 2, p. 229–443. Aramaki, Shigeo, 1956–57, The 1783 activity of Asama Volcano: Japanese Jour. Geology and Geography, v. 27, p. 189–229 and v. 28, p. 11–33. Cameron, W. S., 1964, An interpretation of Schröter's Valley and other lunar sinuous rills: Jour. Geophys. Research, v. 69, no. 12, p. 2423–2430.

Features illustrated (set nos. Japan 1 A–C in northeast corner of photographs).—Central cone of Asama-yama (southwest quadrant of photograph B), one of Japan's most active and dangerous volcanoes, has a deep crater and is bordered on the west by a partial somma (caldera rim). Recent ash covers most ground near crater. Farther away are pyroclastic deposits, loose and gullied (northwest quadrant same photograph) to welded and little dissected (northeast quadrant). Ko-asama-yama, a conical hill (southeast quadrant), is a dome of viscous dacite lava. The Onioshidashi-iwa lava flow of 1783 (east half of photograph A) is hypersthene-augite andesite and has a rough, blocky surface. The flow partly fills the head of a flat-floored, steep-sided trench, the so-called Kambara ditch (northwest quadrant photograph C), carved by a nuée ardente that immediately preceded the lava. Cameron suggests the Kambara ditch as a terrestrial analog of the sinuous rills that occur on the Moon; her figure 5 is an annotated copy of part of photograph B.

Japan 2. Ō-shima Volcano: Volcano Mihara-yama, in an older caldera

Area: Ō-shima (island).
Lat 34°44′ N.; long 139°24′ E.
Number of photographs: 3.
Photograph scale: 1:30,000.
Focal length: 6 in.
Date flown: Sept. 27, 1947.
Map reference: Army Map Service, series L774, sheet 5951 II, Ō-shima sheet, scale 1:50,000.
Geology reference: Foster, H. L., and Mason, A. C., 1955, 1950 and 1951 eruptions of Mihara Yama, O Shima Volcano, Japan: Geol. Soc. America Bull., v. 66, p. 731–762.

Features illustrated (set nos. Japan 2 A–C in west-northwest corner of photographs).—A deep central inner pit in the crater of the volcano Mihara-yama (southwest quadrant of photograph B) has nearly vertical walls. Mihara-yama rises somewhat higher than a surrounding caldera rim, some 2 miles across. The rim is a somma, the highest remaining parts of an ancient volcano which Foster and Mason call Ō-shima Volcano because it makes up most of the island of Ō-shima. The rim rises 10–100 meters above the adjacent caldera floor, except in the northeast quadrant where lavas have poured out onto the outer slopes of the island (see also Japan 3). Plate 1 of Foster and Mason is reduced from photograph B.

Japan 3. Ō-shima Volcano: Explosion craters and lava delta

Area: Ō-shima (island).
Lat 34°43′ N.; long 139°25′ E.
Number of photographs: 5.
Photograph scale: 1:30,000.
Focal length: 6 in.
Date flown: Sept. 27, 1947.
Map reference: Army Map Service, series L774, sheet 5951 II, Ō-shima sheet, scale 1:50,000.
Geology reference: Foster, H. L., and Mason, A. C., 1955, 1950 and 1951 eruptions of Mihara Yama, O Shima Volcano, Japan: Geol. Soc. America Bull., v. 66, p. 731–762.

Features illustrated (set nos. Japan 3 A–E in southeast corner of photographs).—A strait connects Habuminato, a circular harbor surrounded by cliffs some 50 meters high (southeast quadrant of photograph D), to the sea. Foster and Mason believe the harbor is a crater formed by an explosion that occurred when ground water came in contact with hot rock; Hikubo crater, on land nearly a mile to the west resulted from another similar phreatic explosion. In 1778, basaltic lavas that descended eastward from Mihara-yama (volcano with crater in southwest quadrant of photograph B) spilled over a cliff as a lava cascade and built a delta out into the sea. According to Foster and Mason, the cliff is probably a fault scarp. Five parasitic cinder cones are alined about 2 kilometers west of the cliff; these include three in the northeast quadrant of photograph B, and Futago-yama and Tahei-yama, south of center of photograph C. For Mihara-yama, see also Japan 2.

Japan 4. Aso-san and other volcanoes within the same caldera

Area: Kyūshū Island.
Lat 32°53′ N.; long 131°04′ E.
Number of photographs: 5.
Photograph scale: 1:25,000.
Focal length: 6 in.
Date flown: Dec. 7, 1947.
Map reference: Army Map Service, series L772, sheet 4345 IV, Aso San sheet, scale 1:50,000.
Geology reference: Matsumoto, Tadaichi, 1943, The four gigantic caldera volcanoes of Kyûsyû: Japanese Jour. Geology and Geography, v. 19, special number, p. 1–57.

Features illustrated (set nos. Japan 4 A–E in northeast corner of photographs).—More than a dozen complete or partly destroyed craters can be identified on these photographs. These craters include bleached and unbreached cinder cones (photograph A); a lava-filled crater, probably a small caldera, containing a pond (southwest quadrant photograph C); and two complexes of intersecting craters. The eastern complex (southwest quadrant photograph D) has recently been active, as shown by a surrounding blanket of dark ejecta; columns of steam still rise from two fumaroles. Aso-san (southwest quadrant photograph E) stands more than 3,000 feet above the floor of the caldera (north edge of photographs) and 1,000 to more than 2,000 feet above the rim. The caldera in which Aso-san stands is one of the largest recognized, 10 miles across from east to west and 15 miles from north to south. According to Matsumoto, the postcaldera lavas are predominantly augite-andesite (auganite). Japan 5 adjoins this set on the west.

Japan 5. West rim of caldera surrounding Aso-san

Area: Kyūshū Island.
Lat 32°53′ N.; long 130°58′ E.
Number of photographs: 3.
Photograph scale: 1:25,000.
Focal length: 6 in.
Date flown: Dec. 7, 1947.
Map reference: Army Map Service, series L772, sheet 4245 I, Kikuchi sheet, scale 1:50,000.
Geology reference: Matsumoto, Tadaichi, 1943, The four gigantic caldera volcanoes of Kyûsyû: Japanese Jour. Geology and Geography, v. 19, special number, p. 1–57.

Features illustrated (set nos. Japan 5 A–C in northeast corner of photographs).—The western rim of the caldera surrounding Aso-san (through center of photograph B) is 200 to more than 400 meters high. In the southeast quadrant of this photograph Shira Kawa ("White River"), which drains the southern part of the caldera basin, is joined by Kuro Gawa, which drains the interior of the caldera north of the central peaks, and the combined waters flow west through a water gap in the caldera rim (southeast quadrant of same photograph). Kuro Gawa is incised in the lower part of its course, but in northwest quadrant of photograph C it meanders through rice fields. Japan 4 adjoins this set on the east.

Japan 6. Sakura-jima volcano: Young and old lavas on southwest slope

Area: Kyūshū Island.
Lat 31°33′ N.; long 130°38′ E.
Number of photographs: 3.
Photograph scale: 1:30,000.
Focal length: 6 in.
Date flown: Dec. 4, 1947.
Map reference: Army Map Service, series L772, sheet 4241 IV, Kagoshima sheet, scale 1:50,000.
Geology reference: Kotō, Bunjirō, 1916, The great eruption of Sakura-jima in 1914: Tokyo Imp. Univ., Coll. Sci. Jour., v. 38, art. 3, p. 1–237.

Features illustrated (set nos. Japan 6 A–C in northeast corner of photographs).—Minami-take, the southern cone of Sakura-jima, has a deep crater (at north edge of photograph C; for stereo this set must be combined with Japan 7). The upper part of the cone consists largely of pyroclastic materials. Two lava flows have built peninsulas out into Kagoshima-wan (Kagoshima Bay); one of these (near east edge photograph B) is prehistoric; the other, to the northwest, was erupted in 1475–76. North of the latter flow, but not reaching the sea, is a 1749 flow, partly buried by the western 1914 lava flow (north edge of photograph B). The 1914 flow built new land more than a kilometer into Kagoshima-wan toward Kagoshima (northwest quadrant of photograph A), a seaport and the prefectural capital. The lavas of Sakura-jima, like those of the postcaldera peaks at Aso-san, are chiefly augite-andesite.

Japan 7. Sakura-jima volcano: Flow of 1914 on southeast slope

Area: Kyūshū Island.
Lat 31°33′ N.; long 130°42′ E.
Number of photographs: 3.
Photograph scale: 1:30,000.
Focal length: 6 in.
Date flown: Dec. 4, 1947.
Map reference: Army Map Service, series L772, sheet 4241 IV, Kagoshima sheet, scale 1:50,000.
Geology reference: Kotō, Bunjirō, 1916, The great eruption of Sakura-jima in 1914: Tokyo Imp. Univ., Coll. Sci. Jour., v. 38, art. 3, p. 1–237. Matsumoto, Tadaichi, 1943, The four gigantic caldera volcanoes of Kyūsyū: Japanese Jour. Geology and Geography, v. 19, special number, p. 1–57.

Features illustrated (set nos. Japan 7 A–C in northeast corner of photographs).—Sakura-jima (Cherry Island) volcano was an island in Kagoshima-wan (Kagoshima Bay) until 1914, when lavas from its southeast flank joined the island to the mainland (near center of photograph B). The lava came in part from vents at the eastern foot of the breached cone Nabe-yama, built in 1471, and in part from a vent well up on the slope of Sakura-jima. The terminal parts of some of the flows, both on land and in the sea, are highly lobate; in pattern that Kotō compares with the "bird's-foot delta" of the Mississippi. The lava destroyed without trace the previously thriving hot-spring resort, Arimura; its site was on the shore near center of photograph A. According to Matsumoto, Sakura-jima is near the breached south rim of a caldera some 15 miles across; the high ground at center of photograph B is part of the rim. Japan 6 adjoins this set on the west.

Pagan 1. Erosion forms in volcanic materials of Pagan Island

Area: Mariana Islands.
Lat 18°09′ N.; long 145°47′ E.
Number of photographs: 3.
Photograph scale: 1:30,000.
Focal length: 6 in.
Date flown: Feb. 12, 1946.
Map reference: Army Map Service, series W843, sheet 3376 II NW, Shomushon sheet, scale 1:25,000.
Geology reference: Corwin, Gilbert, Bonham, L. D., Terman, M. J., and Viele, G. W., 1957, Military geology of Pagan, Mariana Islands: U.S. Army, Chief Eng., Intelligence Div., Headquarters U.S. Army Japan [Tokyo], 259 p.

Features illustrated (set nos. Pagan 1 A–C in south corner of photographs).—Mount Pagan is a basaltic cone within a somma. Remnants of the caldera rim form inward-facing cliffs to the south, southwest, and north of the summit crater and outward-facing cliffs (formerly sea cliffs) northeast and east of it. Where the sea has breached the rim in west quadrant of photograph B, differential erosion by waves has cut an almost circular cove in the weak tuffs within the caldera. The remnant of the rim north of the cove resembles a tombolo, but the neck that ties it to the mainland is erosional not constructional in origin. Stacks occur along cliffed parts of the shore. Two lakes west of the summit crater mark a subcircular subsidence area; ridges of pyroclastic material within this subsidence are gullied. The young lavas (dark area) that extend northeast from the summit crater are shown at larger scale in Pagan 2.

Pagan 2. Differential soil development on lavas, Pagan Island

Area: Mariana Islands.
Lat 18°09′ N.; long 145°48′ E.
Number of photographs: 2.
Photograph scale: 1:10,000.
Focal length: 12 in.
Date flown: Jan. 16, 1948.
Map reference: Army Map Service, series W843, sheet 3376 II NW, Shomushon sheet, scale 1:25,000.
Geology reference: Corwin, Gilbert, Bonham, L. D., Terman, M. J., and Viele, G. W., 1957, Military geology of Pagan, Mariana Islands: U.S. Army, Chief Eng., Intelligence Div., Headquarters U.S. Army Japan [Tokyo], 259 p.

Features illustrated (set nos. Pagan 2 A, B in north corner of photographs).—Hills covered by coconut palms northwest and southeast of center of photograph A are remnants of a caldera rim (see Pagan 1). Relatively young lava has poured over this rim in a lava cascade (center of photograph). Comparably young lavas cover most of the rest of the photograph; they support vegetation only in patches. According to Corwin (oral commun., 1965), the vegetated patches are places where the original surface was pahoehoe or slab lava; it evidently takes much longer to establish vegetation on the prevailing clinkery aa lava than on pahoehoe. A thick flow of viscous ball aa lava (south quadrant photograph A) stands well above the younger flows, which are more fluid and hence thinner, that lap up around it. Several flows in west quadrant show arcuate ridges. In southwest half of photograph B, lava rivers form a radial pattern on the slope of Mount Pagan.

Pakistan 1. Complex transverse sand dunes south of Khārān Kalāt

Area: West Pakistan.
Lat 28°06′ N.; long 65°15′ E.
Number of photographs: 2.
Photograph scale: 1:40,000.
Focal length: 6 in.
Date flown: 1953.
Map reference: Army Map Service, series U501, sheet 1I–41 X, Khārān Kalāt sheet, scale 1:253,440.
Geology reference: Hunting Survey Corp., Ltd., 1960, Reconnaissance geology of part of West Pakistan; a Colombo Plan cooperative project: Toronto, Geologic map no. 19, Kharan Kalat, scale 1:253,440. (A report published for the Government of Pakistan by the Government of Canada.)

Features illustrated (set nos. Pakistan 1 A, B in southeast corner of photographs).—Major transverse dunes, with sharp crests spaced about half a mile to a mile apart, trend north-northwest; steep northeast-facing slip-off slopes show that the dominant dune-forming wind is from the west-southwest. Several small white patches of salt incrustation indicate that locally a pond sometimes forms at the foot of a dune. The gentle windward slopes of these major dunes have complex patterns of secondary dunes.

Pakistan 2. Mud volcanoes and a faulted plunging anticline

Area: West Pakistan.
Lat 25°27′ N.; long 65°51′ E.
Number of photographs: 5.
Photograph scale: 1:46,000.
Focal length: 6 in.
Date flown: 1953.
Map reference: Army Map Service, series U501, sheet G41–R, Kanrāch sheet, scale 1:253,440.
Geology reference: Hunting Survey Corp., Ltd., 1960, Reconnaissance geology of part of West Pakistan; a Colombo Plan cooperative project: Toronto, Geologic map no. 5, Ormara, scale 1:253,440. (A report published for the Government of Pakistan by the Government of Canada.)

Features illustrated (set nos. Pakistan 2A–E in southeast corner of photographs).—Two conical hills with summit craters, conspicuous in northwest quadrant of photograph E, are about 0.3 mile in diameter. Just south of the southwestern large cone is a smaller but otherwise similar cone, and to the northwest is a feature that appears to be the collapsed remnant of a fourth cone. These cones are mud volcanoes, formed by spattering by natural gas that rose under pressure through the saturated alluvium of the coastal plain. They are approximately on the axial line of an anticline that is cut by several faults where it is exposed to the southwest. The northeast-plunging nose of the anticline is sharply delineated by resistant sandstone layers interbedded with mudstone in the Miocene or Pliocene Hinglaj Formation.

Pakistan 3. Lakes between longitudinal dunes east of Mirpur Khās

Area: West Pakistan.
Lat 25°37′ N.; long 69°35′ E.
Number of photographs: 3.
Photograph scale: 1:35,000.
Focal length: 6 in.
Date flown: 1953.
Map reference: Army Map Service, series U502, Sheet NG42–11, Mirpur Khās sheet, scale 1:250,000.
Geology reference: Hunting Survey Corp., Ltd., 1960, Reconnaissance geology of part of West Pakistan; a Colombo Plan cooperative project: Toronto, Geologic map no. 7, Hyderabad, scale 1:253,440. (A report published for the Government of Pakistan by the Government of Canada.)

Features illustrated (set nos. Pakistan 3 A–C in southeast corner of photographs).—Lakes occupy depressions between long, roughly parallel ridges that trend north-northeast. Most lakes are a few hundred feet wide and less than half a mile long, but half a dozen are ¼–½ mile wide and as much as 2½ miles long. The ridges have forms characteristic of longitudinal sand dunes, but they are evidently stabilized; no active dunes are evident. The agent stabilizing the dunes is not obvious; the sparse growth of bushes they support appears to be too scattered to anchor them securely. The dunes are older than the lakes; the crest of a dune rises as an island within a lake.

Palau 1. Bauxite mines on Babelthuap Island, Palau Group

Area: Caroline Islands.
Lat 7°35′ N.; long 134°35′ E.
Number of photographs: 1.
Photograph scale: Unknown.
Focal length: Unknown.
Date flown: 1944.
Map reference: Figure 3 in geology reference.
Geology reference: Bridge, Josiah, and Goldich, S. S., 1948, Preliminary report on the bauxite deposits of Babelthuap Island, Palau Group: U.S. Geol. Survey for GHQ, Far East Command. See pl. 3 and fig. 4. Bridge, Josiah, and Goldich, S. S., 1948, Bauxite deposits of Babelthuap Island, Palau Group [abs.]: Geol. Soc. America, Bull., v. 59, p. 1313.

Features illustrated (oblique view southeast).—These strip mines were operated by the Japanese between 1938 and 1944. The bauxite was derived by lateritic weathering from volcanic agglomerate of Miocene age. The approximate distribution of bauxite is indicated by the vegetation; where the bauxite is thick it supports ferns rather than trees. The ore came from surficial deposits that averaged only about 7 feet in thickness; mining was by hand methods. The mines are in the northwestern part of Babelthuap (Babeldoab) Island, largest of the Palau Group. Plate 3 of the first geology reference is reduced from this photograph.

Palau 2. Augulpelu Reef, an offshore (barrier) reef

Area: Caroline Islands.
Lat 7°18′ N.; long 134°33′ E.
Number of photographs: 3.
Photograph scale: 1:40,000.
Focal length: 6 in.
Date flown: Jan. 10, 1948.
Map reference: Plate 4 in geology reference.
Geology reference: Mason, A. C., and others, 1956, Military geology of the Palau Islands, Caroline Islands: U.S. Army, Chief Eng., Intelligence Div., Headquarters, U.S. Army Forces Far East [Tokyo], 285 p. See pl. 4.

Features illustrated (set nos. Palau 2 A–C in south corner of photographs).—Augulpelu Reef (central part photograph B) is all under water except the sandbar near north end of the southwestern hook. Coral heads, visible in stereoscopic view, rise to near low-tide level in the lagoon behind the reef. A fringing reef grows along the shore, even where a barrier reef extends offshore. The islands Babelthuap (north corner photograph A) and Garreru (north corner photograph B) are separated from Koror (north corner photograph C) by Toagel Channel. The sea is unusually calm, and breakers on the reef are few and small; on January 10, 1948, this was a lee shore (see Palau 3).

Palau 3. Pitted limestone and living reefs of Eil Malk Island

Area: Caroline Islands.
Lat 7°08′ N.; long 134°23′ E.
Number of photographs: 2.
Photograph scale: 1:40,000.
Focal length: 6 in.
Date flown: Jan. 10, 1948.
Map reference: Plate 4 in geology reference.
Geology reference: Mason, A. C., and others, 1956, Military geology of the Palau Islands, Caroline Islands: U.S. Army, Chief Eng., Intelligence Div., Headquarters, U.S. Army Forces Far East [Tokyo], 285 p. See pl. 4 and pl. 6B.

Features illustrated (set nos. Palau 3 A, B in south corner of photographs).—Solution has deeply pitted the Palau Limestone, of Miocene to Pleistocene age, after it was uplifted to form an island. Many of the solution pits are ponds and lakes. Others are breached and connected to the sea by channels. Elsewhere, remnants of the limestone protrude as islands. According to Gilbert Corwin (oral commun., 1965), all the ponds and lakes are at sea level and have salty water that rises and falls with the tides, although connection with the sea is confined to subterranean openings except in the breached lakes. Living reefs shown include a fringing reef, a barrier reef attached at both ends and enclosing a shallow lagoon, and an offshore barrier reef.

Palau 4. Angaur Island, an uplifted atoll with phosphate deposits

Area: Caroline Islands.
Lat 6°55′ N.; long 134°09′ E.
Number of photographs: 3.
Photograph scale: 1:40,000.
Focal length: 6 in.
Date flown: Jan. 10, 1948.
Map reference: Plate 2 in geology reference. U.S. Hydrographic Office Hydrographic chart 6073.
Geology reference: Irving, E. M., 1950, Phosphate deposits of Angaur Island, Palau Islands: U.S. Geol. Survey for GHQ, Far East Command. 100 p.

Features illustrated (set nos. Palau 4 A–C in south corner of photographs).—The island, about 3 miles across, has had a complex history. Two uplifts are evident from the photographs. The hills in the northwest were a small atoll which was uplifted to form an island. The airfield is on a fringing reef that was built around that island before a second uplift. A new fringing reef is growing and is widest on the west side of the southern peninsula. According to Irving, the actual history is even more complex: the lakes left by phosphate mining extend well below sea level, and when the phosphate was accumulated Angaur must have stood at least 74 feet higher above the sea than today.

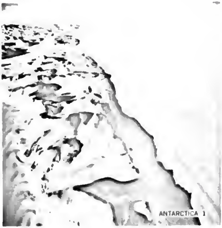
Refracted waves, breakers on the reef flat, and the distribution of whitecaps suggest that surface winds are northwest, although movement of cloud shadows shows that at cloud height the wind is east.

Saudi Arabia 1. Wabar Crater, a small astrobleme

Lat 21°30′ N.; long 50°30′ E.
Number of photographs: 2.
Photograph scale: 1:55,000.
Focal length: 6 in.
Date flown: Nov. 28, 1954.
Map reference: Army Map Service, series K462, sheet NF39W, Northwestern Rub' al Khāli sheet, scale 1:500,000.
Geology reference: Chao, E. C. T., Fahey, J. J., and Littler, Janet, 1961, Coesite from Wabar crater, near Al Hadida, Arabia: Science, v. 133, no 3456, p. 882–883.

Features illustrated (set nos. Saudi Arabia 1 A, B in southeast corner of photographs).—Wabar Crater is a circular depression approximately 300 feet in diameter (less than 0.1 inch at scale of photographs) about 0.8 inch from east edge of the photographs and midway in the area of stereoscopic coverage. The presence of coesite and meteorite fragments identifies it as an astrobleme or meteorite crater. The rim of the crater is distinctly raised, though low; the nature of this raised rim cannot be demonstrated at the scale of the photographs, but analogy with Meteor Crater, Ariz., suggests it is partly upturned bedrock and partly ejecta. The entire area is one of dunes trending irregularly east-northeast. Most of these are normal transverse dunes formed by northwest winds, but a few are sharp ridges with depressions (suggesting wind scour) on their southeast sides; possibly these sharp ridges reflect the effect of southeast winds that alternate with the prevailing or stronger northwest winds.

REPRESENTATIVE AERIAL PHOTOGRAPHS



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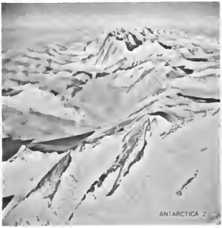

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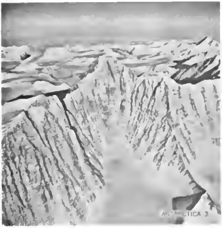

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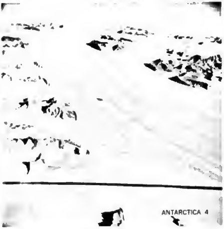

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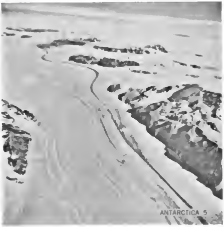

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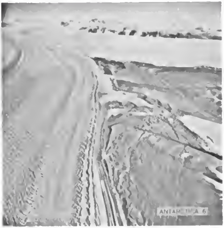

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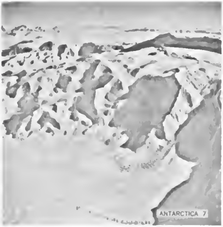
Antarctica 7–12



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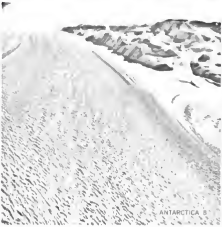

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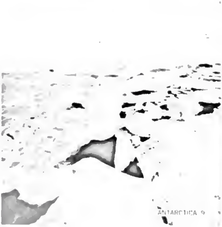

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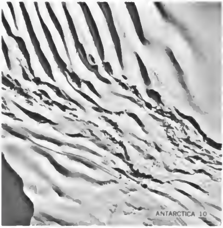

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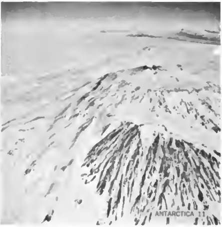

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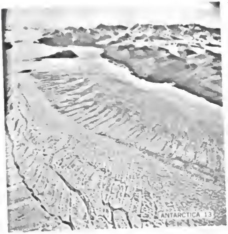
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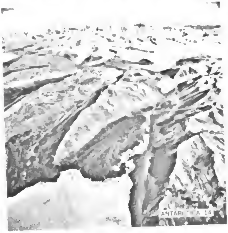
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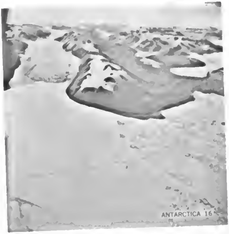
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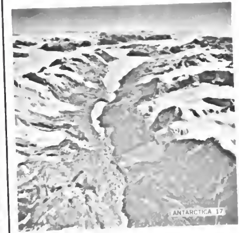
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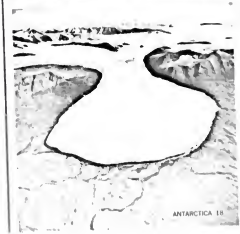
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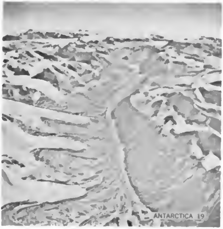
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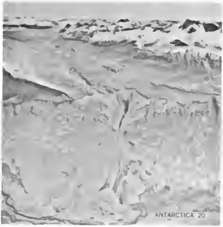
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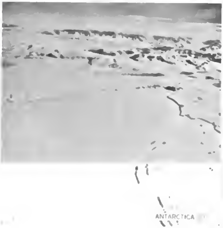
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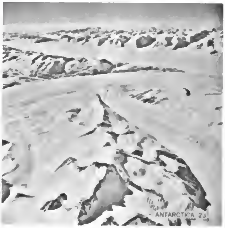
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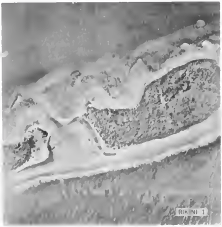
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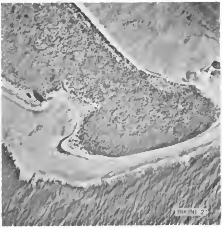
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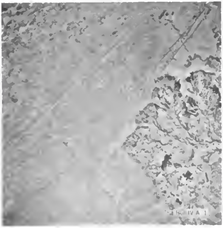
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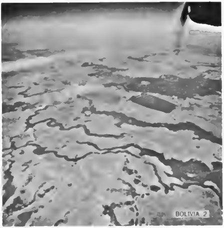
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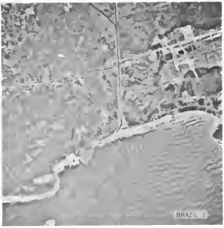
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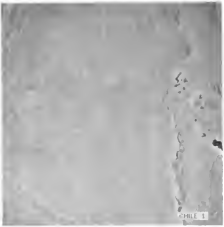
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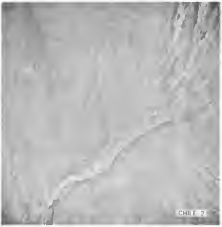
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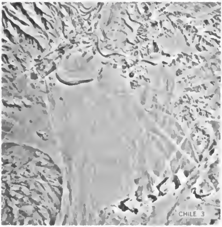
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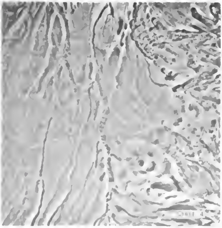
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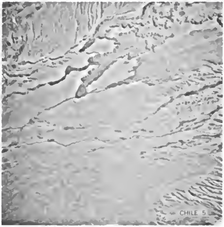
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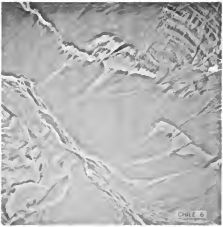
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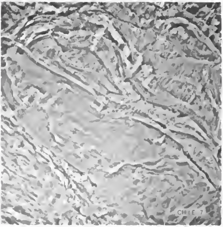
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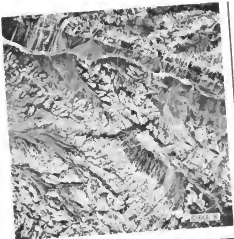
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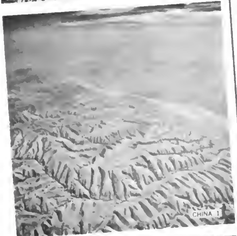
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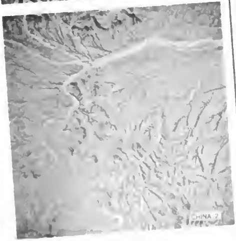
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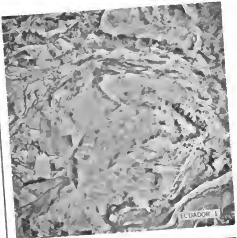
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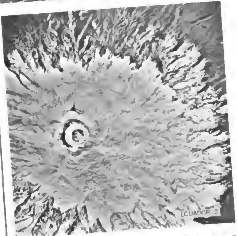
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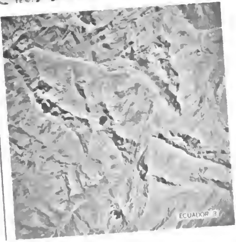
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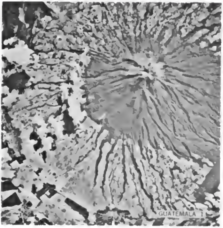
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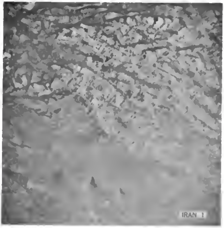
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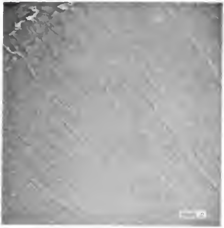

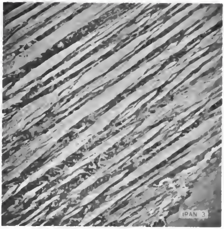
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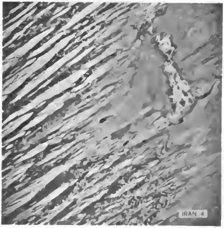
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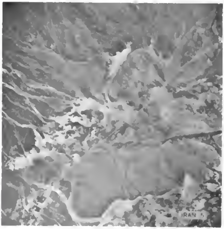
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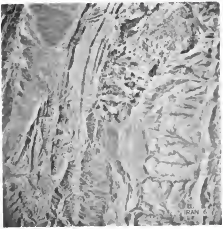
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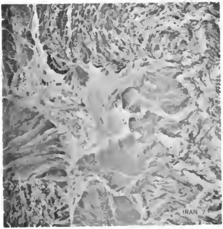
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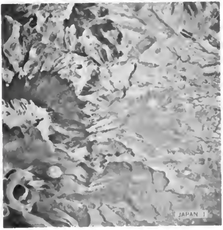
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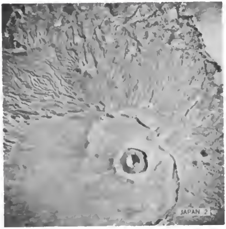
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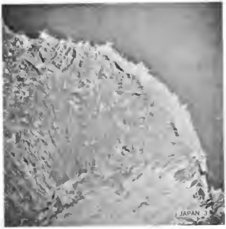
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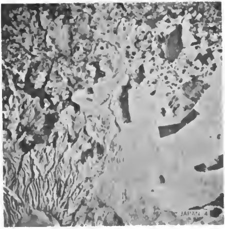
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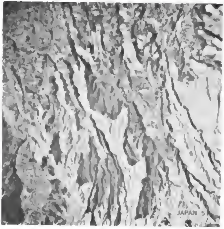
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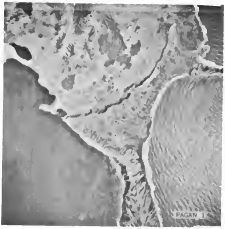
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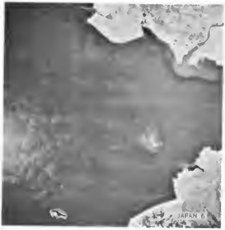
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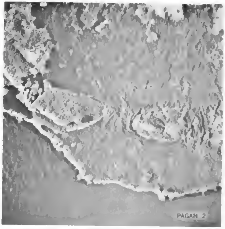
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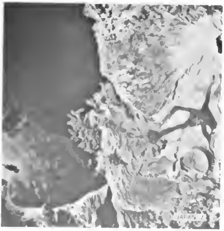
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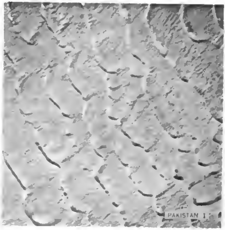
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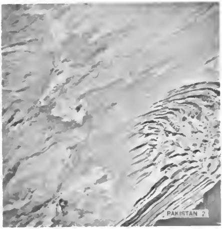

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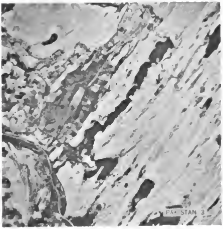

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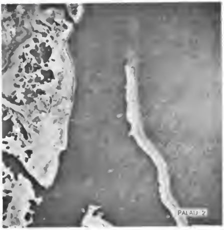

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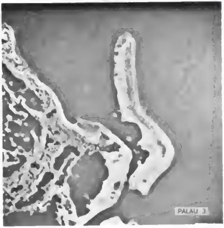

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Stratigraphy of the Star Peak Group (Triassic) and Overlying Lower Mesozoic Rocks Humboldt Range, Nevada

GEOLOGICAL SURVEY PROFESSIONAL PAPER 592

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By N. J. SILBERLING *and* ROBERT E. WALLACE

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TABLE

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STRATIGRAPHY OF THE STAR PEAK GROUP (TRIASSIC) AND OVERLYING LOWER MESOZOIC ROCKS, HUMBOLDT RANGE, NEVADA

By N. J. Silberling and Robert E. Wallace

ABSTRACT

The Star Peak Group and other, still younger, lower Mesozoic rocks of the "Winnemucca sequence" of Silberling and Roberts form roughly half the bedrock exposures in the Humboldt Range, which occupies parts of the Imlay, Unionville, and Buffalo Mountain quadrangles in northwestern Nevada. These strata, aggregating more than 10,000 feet in thickness, are largely marine sedimentary rocks that overlie with subtle angular unconformity the predominantly volcanic Koipato Group of Permian to earliest Triassic age. Exposures of the Star Peak Group roughly encircle the central part of the range and are most extensive at its north and south ends. The Star Peak Group, comprising the Prida and Natchez Pass Formations, is characterized by calcareous rocks whose composition contrasts sharply wth that of the overlying formations, which are composed mainly of fine-grained terrigenous clastic rocks.

The Prida Formation, the lower formation of the Star Peak Group, is divided into three informal members. Its lower member is lithologically heterogenous and includes a variety of calcareous terrigenous clastic rocks and impure carbonate rocks above a basal clastic unit of noncalcareous sandstone and conglomerate. Lateral lithologic changes within the lower member and variation in its thickness from a few tens of feet to several hundred feet reflect the original slope and topographic irregularity of the eroded surface of the underlying rocks of the Koipato Group. In the northern part of the Humboldt Range, much of the lower Prida is locally cut out against two prominent basement highs that coincide in location with intrusive parts of the Koipato volcanic pile and with the principal silver deposits in the Star Peak rocks. Elsewhere in the northern part of the range, where the lower member of the Prida is thickest and was first deposited, the lower member includes at least two successive ammonite faunas of Spathian (latest Early Triassic) age.

The middle member of the Prida similarly ranges in thickness, locally attaining a maximum of 400 feet in the northern part of the range, but it is lithologically uniform and everywhere consists of gray, commonly highly fossiliferous limestone interbedded with calcareous shale and siltstone. It preserves a uniquely complete sequence of ammonite faunas representative of early, middle, and late Anisian (early Middle Triassic) time.

The upper member of the Prida shows pronounced lateral variation in its thickness and age, progressively thickening from 100 feet in the southern part of the range, where it is wholly Ladinian (late Middle Triassic) in age, to 2,000 feet or more in the northwestern part of the range, where it ranges from early Ladinian to early Karnian (earliest Late Triassic) in age. The upper Prida is composed of evenly parted dark cherty laminated limestone (or, more rarely, dolomite) having some interbedded units of massive organic-detrital carbonate rocks. Fossils are scarce and except for sponge spicules, exclusively of planktonic invertebrates. Lateral changes in the thickness and age of the upper Prida are compensated for by changes in the thickness and age of the massive organic-detrital carbonate rocks that form the lower part of the overlying Natchez Pass Formation. The upper Prida and part of the lower Natchez Pass are therefore interpreted as interfingering facies of one another, the upper Prida being the deposit that accumulated farther from shore and in deeper water.

Within the Natchez Pass Formation, which forms the upper formation of the Star Peak Group, two members are recognized throughout most of the Humboldt Range. The lower member consists mainly of massive thick and very thick bedded carbonate rocks except in the southern part of the range, where roughly half of its 1,500-foot thickness is made up of mafic volcanic rocks. Farther north in the range, where the lower Natchez Pass is largely supplanted by the upper Prida, the thickness of the lower Natchez Pass is as little as 400 feet.

The upper member of the Natchez Pass is about 1,000 feet thick wherever recognized in the Humboldt Range. In most of the range, brown-weathering impure silty limestone forms its lower part and abruptly, and perhaps disconformably, overlies the lower member. These impure limestones grade upward into an approximately equal thickness of massive thick-bedded relatively pure carbonate rock resembling that of the lower member.

Although these two members cannot be recognized among the structurally deformed carbonate rocks of the Natchez Pass at the northeastern tip of the range, about 400 feet of interbedded chert conglomerate, sandstone, and calcareous siltstone in the middle part of the section there may be a coarse clastic equivalent of the impure limestone that forms the lower part of the upper member farther south.

In the southern part of the range, the Natchez Pass contains fossils of probable early Karnian (earliest Late Triassic) age in its middle part and probably includes beds ranging from late Ladinian to late Karnian in age. Farther north, where the lower Natchez Pass is thinnest, the formation may be entirely late Karnian in age.

Overlying the Star Peak Group at both ends of the Humboldt Range is the Grass Valley Formation, whose estimated thickness is a few thousand feet. Dark chlorite-bearing noncalcareous pelitic rocks and sandstone characterize the Grass Valley, which is unfossiliferous except for occasional plant remains. Sandstone interbedded with the pelitic rocks accounts for about one-third of the total thickness and is of two generally different kinds. The more common kind is dark thin-bedded very fine grained micaceous sandstone that occurs in laterally discontinuous units throughout the section. Bedding surfaces, both in the Humboldt Range and to the northeast in the East Range, commonly bear linguoid ripple marks and other sedimentary features that indicate uniform northwest-trending current directions. Less common than the impure sandstone is clean medium-grained sandstone. It occurs in laterally persistent units, generally a few tens of feet thick, and may represent beach and bar deposits. The Grass Valley is similar in composition to much of the upper part of the lower Mesozoic section in northwestern Nevada, in which rapidly deposited fine-grained terrigenous clastic sedimentary rocks predominate. Regional facies changes, composition, sedimentary structures, and stratigraphic position between shallow-water marine carbonate rocks suggest that the Grass Valley is part of a prograding deltaic complex related to major river drainage that flowed into northwestern Nevada from the east.

The upper part of the Grass Valley, together with younger rocks, is preserved only in the Pershing mining district at the southern tip of the Humboldt Range. There, the uppermost several hundred feet of the formation is repeated by large-scale overturned folds. Unlike most of the Grass Valley, this upper part weathers orange and red, is partly calcareous, and locally contains marine fossils, including ammonites of early middle Norian (late Late Triassic) age.

The Grass Valley grades upward into carbonate rocks of the Dun Glen Formation. The Dun Glen ranges in thickness from several tens of feet to a few hundred feet in the Pershing district, but is considerably thicker in mountain ranges farther east in northwestern Nevada. Most of the Dun Glen is well-bedded massive limestone that locally contains a large and diverse assemblage of shallow-water marine invertebrates and calcareous algae. Where the formation is thickest, its upper part consists of intraclastic limestone or dolomitic sedimentary breccia.

The post-Dun Glen lower Mesozoic strata in the Pershing district are divided into two informal map units, the lower of which consists mainly of orange- and red-weathering partly calcareous pelitic rocks, siltstone, and sandstone resembling the uppermost Grass Valley Formation in the same area. Owing to structural complications, the thickness of the lower unit of post-Dun Glen strata is uncertain, but it is thought to be about 2,000 feet. At one place a large ammonite fauna of late middle Norian age was obtained from near the base of the lower unit. In the part of the Pershing district where the underlying Dun Glen Formation is relatively thin, a conspicuous unit of dolomite conglomerate up to 100 feet thick occurs a few hundred feet above the base of the lower unit of post-Dun Glen strata. The mercury deposits of the Pershing district are largely restricted to this dolomite conglomerate and to the limestone and dolomite sedimentary breccia that forms the upper part of the thick Dun Glen sections in other parts of the district.

The upper unit of post-Dun Glen strata is lithologically heterogeneous and includes a variety of calcareous siltstones and sandstones, limestones, and pelitic rocks having an aggregate exposed thickness of more than 1,000 feet. Upper Norian (upper Upper Triassic) ammonites and the pelecypod *Monotis subcircularis* occur at several places in its lower part. Ammonites indicative of both the lower and the upper parts of the Lower Jurassic have also been found in isolated exposures of strata that are included in the upper unit and are the youngest pre-Tertiary strata in the Humboldt Range.

INTRODUCTION

The Star Peak Group and the other lower Mesozoic strata that overlie it form the "Winnemucca sequence" of Silberling and Roberts (1962), one of several distinct sequences of largely marine lower Mesozoic rocks that characterize different parts of northwestern Nevada. In the Humboldt Range, whose geographic setting is shown in figure 1, rocks of the "Winnemucca sequence" aggregate more than 10,000 feet in thickness and, together with the underlying dominantly volcanic Koipato Group, form by far the largest part of the bedrock exposures.

The succession of lower Mesozoic rock units and their variations in thickness from one end of the range to the other are illustrated diagrammatically in figure 2. The age relations of these rock units are shown in figure 3.

These lower Mesozoic strata of the "Winnemucca sequence" roughly encircle the central part of the Humboldt Range and delineate its major structure, which is a large-scale much-deformed anticlinal fold whose axis strikes somewhat northeast of the general north trend of the range. Calcareous rocks of the Star Peak Group—that is, the lower part of the "Winnemucca sequence"—border the range on either side and dip away from the older rocks of the Koipato Group that are in the anticlinal core of the range. Toward either end of the range, strata of the "Winnemucca sequence" are more widely and completely exposed. In the northern part of the range, they form the stucturally complex and partly overturned west limb of the major anticlinal structure, and at the southern end of the range they wrap around the southward-plunging axis of this fold and are involved in northwest-trending folds that apparently truncate the major northeast-trending anticline. The higher parts of the "Winnemucca sequence" that overlie the Star Peak Group at the north end of the Humboldt Range are represented by the Grass Valley Formation; at the south end of the range they include the Grass Valley and Dun Glen Formations and still younger, unnamed beds of latest Triassic and Early Jurassic age. As elsewhere, these higher parts of the "Winnemucca sequence," though partly calcareous, are composed mainly of fine-grained terrigenous clastic rocks.

The Humboldt Range affords an unusually good opportunity to study the "Winnemucca sequence"—particularly its lower part—because these rocks are contained in a single continuously exposed structural block nearly 40 miles long. Probably nowhere else in northwestern Nevada can lateral changes among the scattered exposures of lower Mesozoic rocks be studied over so great a distance without risk of overlooking large-scale structural rearrangement. Another notable feature of the "Winnemucca sequence" in the Humboldt Range is its generally more marine character in comparison with the related rocks in the ranges to the east. Thus, marine faunas found in the Humboldt Range provide relatively precise age assignments for several different parts of the "Winnemucca sequence" whose ages elsewhere have been uncertain.

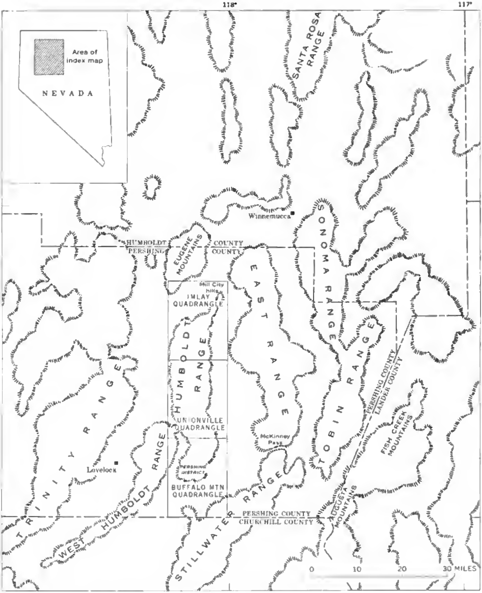


FIGURE 1.—Location of the Humboldt Range and the Imlay, Unionville, and Buffalo Mountain 1:62,500 quadrangles in relation to other nearby geographic features referred to in text.

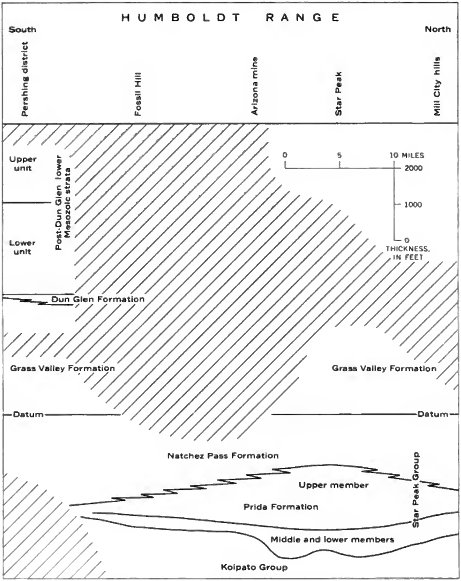


FIGURE 2.—Succession of lower Mesozoic rock units in the Humboldt Range showing the thickness and representation of the units from the south end of the range to the north end. Diagonal ruling indicates parts of the rock record that have been removed by erosion or that are obscured by younger deposits or by structural complications.

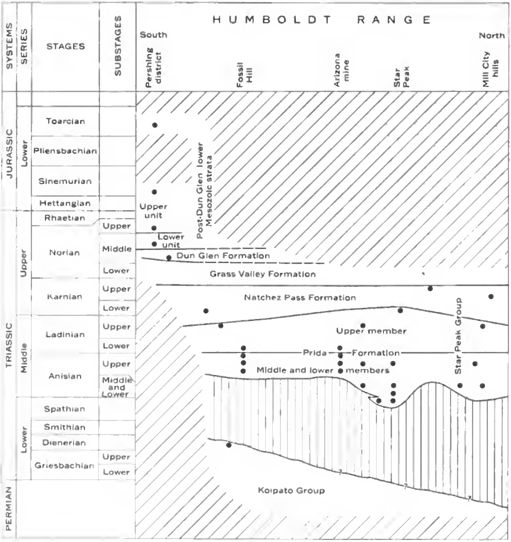


FIGURE 3.—Time-stratigraphic correlation and lateral variations in the age of the lower Mesozoic rock units in the Humboldt Range. Solid dots represent the occurrence of age-diagnostic fossils. Vertical ruling indicates stratigraphic hiatus; diagonal ruling, lack of data.

FIELDWORK AND GEOLOGIC MAPPING

The present report stems from two larger programs, one concerned with the geology and mineral deposits of the Buffalo Mountain, Unionville, and Imlay 1:62,500 quadrangles, and a second concerned with the Triassic System in North America. Fieldwork in the Humboldt Range was done by the writers and D. B. Tatlock largely during the summers of 1956–59 but also during subsequent shorter visits to the area.

The part of the Humboldt Range that lies within the Imlay quadrangle, including the type locality of the Star Peak Group, was mapped geologically on field sheets at a scale of 1:24,000. Those areas where rocks of the "Winnemucca sequence" crop out in the northeastern and southeastern parts of the range within the Unionville quadrangle were mapped on field sheets at 1:12,000; elsewhere in this quadrangle, mapping was at a scale of 1:48,000. Likewise, the areas of "Winnemucca sequence" outcrop in the southeastern part of the range within the Buffalo Mountain quadrangle, as well as parts of the Pershing district within this quadrangle, were mapped in the field at 1:12,000; the other parts of the Buffalo Mountain quadrangle were mapped at 1:48,000.

This mapping, which documents the present stratigraphic study, is incorporated in the separately published geologic quadrangle map of the Imlay quadrangle (Silberling and Wallace, 1967) and in the yet unpublished Unionville and Buffalo Mountain quadrangle maps being prepared by R. E. Wallace, N. J. Silberling, and D. B. Tatlock. The geologic quadrangle maps of the Buffalo Mountain and Unionville quadrangles are to supersede the preliminary geologic maps of these areas published previously (Wallace and others, 1959, 1960).

Most of the stratigraphic thicknesses given in the descriptions of these lower Mesozoic strata are based on the geologic-map relations of the strata. For the most part, detailed measured sections of the rocks are meaningless, as the units are thick, monotonously uniform and lacking marker horizons, and locally poorly exposed and structurally complex.

ACKNOWLEDGMENTS

Previous geologic research that touched on some aspect of the "Winnemucca sequence" in the Humboldt Range began with the pioneer studies of the 40th Parallel Survey (Hague and Emmons, 1877; King, 1878) and included studies by Hyatt and Smith (1905), Ransome (1909), Smith (1914) and Knopf (1924). The report by Cameron (1939) concerning the geology of a large area in the northeastern part of the range was especially helpful.

The Humboldt Range is one of the few stratigraphically significant areas that escaped rigorous study by Dr. S. W. Muller, of Stanford University and the U.S. Geological Survey, during his researches on the lower Mesozoic of northwestern Nevada. Nevertheless, Professor Muller gave considerable aid—based on his reconnaissance in various parts of the range—in directing the writers to localities of critical geologic and paleontologic interest.

Dr. Stanisław Dzułynski, of the Polish Academy of Sciences, visited various exposures of the Grass Valley Formation and related rocks in the vicinity of the Humboldt Range during 1958 in company with Silberling. His help in interpreting the depositional history of these rocks is gratefully acknowledged.

Dr. E. T. Tozer, of the Geological Survey of Canada, provided invaluable advice on the identification and age assignment of the Triassic molluscan faunas at various times during the course of this study and during a visit to the area in 1964.

TERMINOLOGY

The conventions of terminology used in the following stratigraphic descriptions are those proposed by Wentworth (1922) for the grain size of clastic sedimentary rocks, by Goddard and others (1948) for rock colors, and by Ingram (1954) for the thickness of stratification and parting units in sedimentary rocks. The term "massive" is applied to rocks characterized by relatively thick beds that lack apparent internal compositional variations or structures.

Most of the lower Mesozoic carbonate rocks of the Humboldt Range have undergone some degree of recrystallization, but insofar as possible the terminology used for limestones follows the classification of Folk (1959, 1962), and the crystallinity of carbonate rocks is expressed according to the scheme recommended by Folk (1962).

All U.S. Geological Survey Mesozoic fossil localities in the Humboldt Range that are cited by number in the text are either plotted on the geologic quadrangle maps or related on plate 1 to plotted localities.

STAR PEAK GROUP

The Star Peak Group, for which Star Peak in the northern Humboldt Range is the type locality, comprises the predominantly calcareous Prida and Natchez Pass Formations, whose typical exposures are in the East Range. In the Humboldt Range these formations are locally nearly 4,000 feet in combined thickness and range from latest Early Triassic to medial Late Triassic in age. The Prida Formation rests unconformably on the Koipato Group, and its lower part consists of impure carbonate rocks and calcareous clastic rocks whose composition and thickness vary from place to place. Laminated cherty limestone and dolomite form most of the upper part of the Prida, whose thickness ranges greatly in the Humboldt Range and varies inversely with the thickness of the lower part of the overlying Natchez Pass Formation. Massive thick-bedded organic-detrital carbonate rocks characterize the Natchez Pass, but generally subordinate amounts of volcanic rocks, terrigenous clastic rocks, and impure limestone are also present, particularly in its middle part. Mafic volcanic rocks and related dikes occur at various levels within the Star Peak Group, but they add little to its thickness except in the southwestern part of the range, where volcanic flows, tuffs, and breccias constitute about half of the Natchez Pass Formation.

The Star Peak was originally described in the reports of the 40th parallel survey by King (1878, p. 269, 273–277) and Hague and Emmons (1877, p. 723–727) as a group consisting of an alternating succession of three thick limestone units and three equally thick quartzite units. These were thought to represent the upper part of the Triassic, to total nearly 10,000 feet in thickness, and to conformably overlie the Koipato Group, which was described as a thick succession of argillites, quartzites, and their metamorphic equivalents. The lowest unit of the Star Peak was described as the limestone resting on the Koipato near the mouth of Star Canyon on the east side of the range. Successively higher units were recognized westward up to the crest of the range, and the highest quartzite unit of the Star Peak was said to occupy the upper part of Humboldt Canyon on the west side of the range. This quartzite unit, in turn, was thought to be conformably overlain toward the mouth of Humboldt Canyon by a limestone unit and a slate unit, both of which were dated as Jurassic.

The section of the Star Peak as described by King and Hague and Emmons was briefly commented upon by Hyatt and Smith (1905, p. 21), who pointed out that unrecognized repetition by faulting had resulted in an exaggeration of the thickness of the section. Ransome (1909, p. 32) noted that considerable revision of the original description was needed and was the first to recognize the dominantly volcanic character of both the Koipato and the "quartzite" units included in the typical section of the Star Peak.

The Star Peak Formation was revised by Cameron (1939, p. 580–583) on the basis of reconnaissance geologic mapping in the northeastern part of the Humboldt Range. Cameron demonstrated that the "quartzite" units originally included in the Star Peak represent Koipato volcanic rocks repeated by strike faulting, and the Star Peak was redefined as comprising the mainly calcareous Middle and Upper Triassic strata overlying the Koipato. Recognizing that the upper limit of the Star Peak is not exposed in the area studied by him, Cameron selected as the most complete sequence the limestones exposed on the east face of Star Peak from the outcrops of the Koipato in American Basin up to the summit (fig. 4). This sequence was described as a continuous section formed by three successive limestone members with a total exposed thickness of about 3,500 feet, but subsequent mapping with the advantage of more stratigraphic and structural control from surrounding areas showed that these limestones on the east side of Star Peak are both broken by faults and partly repeated by a large fold. In fact, in the northern part of the Humboldt Range no continuous section of the carbonate rocks included here in the Star Peak Group is exposed, nor has a reliable composite section of the entire group been pieced together, owing to the scarcity of marker beds within the thick section and to the complex structure.

The Star Peak "group" of King or "formation" of Cameron in its type area is thus not amenable to revision in terms of a standard section; fortunately, the need for adequately defined units of formation rank in this part of the section is fulfilled by the Prida and Natchez Pass Formations established by Muller, Ferguson, and Roberts (1951) for exposures in the nearby ranges to the east. These formations are readily recognized in the Humboldt Range, though some notable lateral variations exist. As the various limestone exposures originally included in the Star Peak are all assignable to parts of the Prida or Natchez Pass Formations, the name Star Peak is retained in this paper for a group embracing these two formations. This is a natural grouping and emphasizes the contrast between these predominantly calcareous formations and the overlying lower Mesozoic formations, which are composed mainly of fine-grained terrigenous clastic rocks.

In the Humboldt Range, as in the ranges farther east, the Star Peak Group is conformably overlain by the Grass Valley Formation composed of metapelitic rocks and sandstones of medial Late Triassic age. The so-called Jurassic limestone that in the interpretation of King (1878, p. 294–295) was supposed to overlie the highest "quartzite" unit of the "Star Peak Triassic" in Humboldt Canyon is, like the limestone units within King's Star Peak "group," a structural mixture of different parts of the Prida and Natchez Pass Formations. The "Jurassic slates," which in turn were thought to overlie this so-called Jurassic limestone unit, belong to

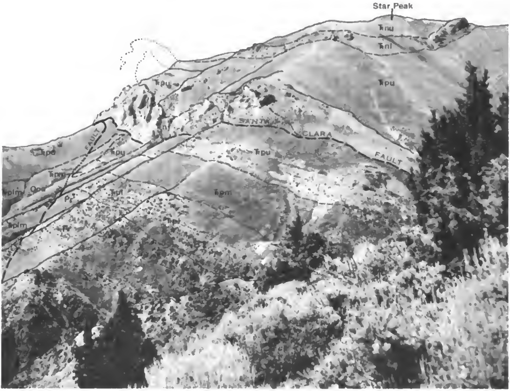


FIGURE 4.—East flank of Star Peak. Rocks exposed form part of the Star Peak Group as originally described by King (1878) and were subsequently used by Cameron (1939) as the basis for redefinition of the group. Rock units as labeled are: Rochester Rhyolite (Pr); Prida Formation, comprising the lower member (Ŧpl) and middle member (Ŧpm), or the undifferentiated lower and middle members (Ŧplm), and the upper member (Ŧpu); Natchez Pass Formation, including the lower member (Ŧnl) and upper member (Ŧnu); and Quaternary older alluvial deposits (Qoa).

the Grass Valley Formation. Thus the rocks upon which King (1878, p. 269) based his statement that in the Humboldt Range "the Trias and the Jura are perfectly conformable" actually have no bearing on the Triassic-Jurassic boundary.

PRIDA FORMATION

The Prida Formation as established by Muller, Ferguson, and Roberts (1951) has the northeastern East Range as its type locality. The somewhat deformed and laterally variable section in the East Range has not been described in detail, but in general the Prida at its type locality includes (1) a lower unit that consists of 10–50 feet of basal sandstone and conglomerate, derived from the underlying Koipato Formation, overlain by 50–100 feet of brown-weathering massive silty and sandy dolomite; (2) a middle unit of about 150 feet of calcareous shale and siltstone with interbeds of gray limestone; and (3) an upper unit of about 100 feet of regularly bedded dark-gray cherty limestone transitional into the overlying mostly massive dolomite and limestone of the Natchez Pass Formation.

In the Humboldt Range, exposures of the Prida Formation almost encircle the rocks of the Koipato Group that occupy the core of the broad anticlinal fold in the central part of the range. The Prida crops out intermittently along the southeast flank of the range from American Canyon south to Fisher Canyon; from there it swings westward, crosses Black Ridge in a narrow outcrop band, and then continues from the north end of Packard Flat northward along the west flank of the range. North of the latitude of Rocky Canyon, in the northern part of the Unionville quadrangle and in the Imlay quadrangle, the Prida is widely exposed in the higher parts of the range, where it forms part of the structurally complex northwestern limb of the same large-scale anticlinal fold.

In the southern part of the Humboldt Range—for example, on the east slope of Black Ridge within the Buffalo Mountain quadrangle—the lithologic succession and thickness of the Prida Formation are about the same as in its type area in the northeastern East Range. Though not everywhere shown on the geologic map, three informal subdivisions, termed the lower, middle, and upper members can be recognized; these correspond to the three units given for the type locality. In this part of the Humboldt Range, as in the northern East Range, the Prida is wholly Middle Triassic, ranging from late Anisian to Ladinian in age. (See fig. 3.)

Farther north in the Humboldt Range, the thickness of the Prida increases markedly and progressively, attaining a maximum of over 2,500 feet in the northwestern part of the range. Although the same three members can be recognized, the gross aspect of the formation differs considerably from that farther south in the Humboldt Range or in the East Range owing to pronounced differences in the relative thickness of the different members. Several hundred feet of this increase in thickness within the Humboldt Range results from lateral variations in the lower and middle members; these variations reflect the configuration of the preexisting erosional surface of the underlying Koipato Group. Locally, in the northern part of the range, deposition of the Prida began as early as the Spathian (latest Early Triassic), and the lower and middle members are each as much as 400 feet thick. Most of the increase in thickness of the formation, however, results from thickening of the upper member at the expense of the overlying Natchez Pass Formation. (See fig. 2.) The thick sequence of dark laminated cherty limestone that forms the upper member of the Prida includes beds as young as earliest Karnian (earliest Late Triassic) in the northwestern part of the range and is interpreted to be in large part a relatively offshore, deeper water facies of the massive carbonate rocks that form the lower part of the Natchez Pass Formation and have their greatest thickness in the southern part of the range.

The Prida Formation in the Humboldt Range, like that in the nearby ranges to the east (Muller and others, 1951; Ferguson and others, 1951), rests unconformably on the Koipato Group. Angular discordance is shown by gradual truncation of units within the Koipato beneath the unconformity, but the amount of discordance is too small for measurement in any one exposure. At many places in the range, the basal beds of the Prida are conglomerate and sandstone composed of detritus from the underlying Koipato, and they are indicative of a period of erosion preceding deposition of the Star Peak Group as noted by Wheeler (1939, p. 106–107) and Cameron (1939, p. 580). Starting with King (1878, p. 269), early workers were influenced by the lack of obvious discordance between the Koipato and Star Peak and were misled by the inclusion of fault slivers of Koipato rocks in the typical Star Peak section. Consequently, they regarded the two sequences as conformable and assigned the Koipato to the lower part of the Triassic. The strong argument by Knopf (1924, p. 30) for conformity between, and even contemporaneity of the limestones of the Star Peak and volcanic rocks of the underlying Koipato was based on exposures on the west flank of Black Ridge, where the nature of the contact between these groups is indeed deceiving. Here, the Weaver Rhyolite at the top of the Koipato includes a thick clastic unit that is unique in containing a few beds of limestone; the highest unit of the Weaver is a mixture of rhyolite felsite and clastic rocks indistinguishable from the sheared basal clastics of the Prida; the section of the Prida is the thinnest in the range; and most of the overlying Natchez Pass Formation is composed of volcanic flows, breccias, and tuffs rather than the carbonate rock more characteristic of the formation. All of these units, however, can be traced northeastward to the east side of the range, where the unconformable relation between the Prida Formation and the underlying Weaver Rhyolite is more apparent. Beneath the Prida near the mouth of Fisher Canyon the highest unit of the Weaver is a rhyolite felsite which is successively underlain by a clastic unit, another felsite unit, and another clastic unit. On the north side of Troy Canyon, 2 miles farther north, the upper felsite unit is absent, and the Prida rests on the underlying upper clastic unit. Between Troy and South American Canyons, this upper clastic unit in turn thins northward beneath the unconformity until it feathers out, and the Prida ultimately rests on the lower felsite unit. This progressive truncation of the Koipato agrees with the general trend, first observed by Cameron (1939, p. 579), for the Star Peak Group to progressively overlie stratigraphically lower parts of the Koipato toward the north end of the range.

Only several hundred feet of the Rochester Rhyolite separates the Prida Formation from greenstones assigned to the lowest formation of the Koipato Group, the Limerick Greenstone, in the northeastern part of the range, whereas a thick section of Rochester Rhyolite underlies the Prida in the central part of the range; at the south end of the range, both the Rochester and the overlying Weaver Rhyolite, which total several thousand feet, intervene between the Limerick Greenstone and the base of the Star Peak Group. Considerable erosion of the Koipato Group in the northern Humboldt Range prior to deposition of the Prida Formation is further suggested by exposures in and around Humboldt Canyon, where the Prida rests both on the Rochester Rhyolite and on sills of rhyolite prophyry within the Rochester that are interpreted as feeder dikes for higher parts of the Koipato Group such as the Weaver Rhyolite at the south end of the range. The greater depth to which the Koipato in the northern part of the range was eroded prior to Star Peak deposition, together with the general north to south transgression of the Star Peak over the eroded surface of the Koipato, results in a somewhat different stratigraphic hiatus at the unconformity between the Star Peak and Koipato Groups in different parts of the range. To the north, the hiatus represents latest Permian to late Early Triassic time, but to the south it represents early Early Triassic to early Middle Triassic time.

LITHOLOGIC DESCRIPTION

LOWER MEMBER

The lower member of the Prida Formation shows marked lateral variations in thickness, composition, and age within the Humboldt Range. (See pl. 2.) These variations reflect a general southward transgression of the Star Peak seas across the eroded surface of the Koipato Group, upon which local topographic highs stood as islands or peninsulas during the initial phases of Prida deposition.

Though lithologically hetergeneous, the lower member consists mainly of calcareous and dolomitic siltstone and sandstone or silty and sandy limestone and dolomite, the relative proportions varying from place to place. Noncalcareous terrigenous clastic rocks and conglomerate are generally confined to the basal part of the member and rarely exceed a few tens of feet in thickness. Relatively pure carbonate rocks form a minor part of the thicker sections, and volcanic rocks are found within the lower member in one small part of the Humboldt Range.

The more abrupt lateral changes in the lower member occur in the northern part of the Humboldt Range, where the member was first deposited and attains its greatest thickness and yet locally is largely cut out against two prominent highs on the Koipato basement. One of these basement highs is in the northwestern part of the range and is centered around the head of Star Canyon and the upper parts of Humboldt and Imlay Canyons, and the other extends through the Arizona mine area near Unionville on the east side of the north-central part of the range. For brevity, these features are termed, respectively, the Star-Humboldt basement high and the Arizona basement high. Their configurations, as indicated by lateral variations in the thickness of the lower member of the Prida Formation, are shown in figure 9. (See section on paleogeographic interpretation, p. 25.)

Away from these basement highs, thick sections of the lower member of the Prida crop out in two separate areas in the northern part of the range: along the east flank from Buena Vista Canyon northward, and on the west side of the range between Ryepatch and Eldorado Canyons. In both of these outcrop areas, the character of the lower member is generally alike; presumably this relatively thick lower Prida section is continuous across the range, although the lower member is concealed beneath younger Star Peak rocks at the head of Coyote and Buffalo Canyons between the Star-Humboldt and Arizona basement highs.

The lower Prida sections on both sides of the range are as much as 400 feet thick and are composed of three distinct lithologic units: a basal unit of terrigenous clastic rocks, an intermediate unit of carbonate rocks, and an upper, distinctive brown-weathering calcareous sandstone and siltstone termed the brown calcareous sandstone unit. Of these, the basal clastic unit ranges in thickness from several feet to about 100 feet. Well stratified noncalcareous sandstone is prevalent in addition to poorly sorted grit and fine-grained conglomerate composed of debris from the underlying Koipato. The basal clastics are thickest and coarsest in grain size near the highs on the surface of the underlying Koipato. The coarsest clastics were observed at the base of the lower member near the mouth of the North Fork of Straight Canyon on the northwest flank of the Arizona basement high. Here, much of the basal clastic unit is a boulder conglomerate formed of flow-banded rhyolite felsite from the locally underlying Rochester Rhyolite.

The carbonate unit, above the basal clastic unit, attains a maximum thickness of about 300 feet near the east front of the range between Coyote and Bloody Canyons. It is variable in composition but consists largely of silty or sandy gray limestone irregularly interbedded with subordinate units of yellow-brown or reddish-brown calcareous siltstone and sandstone. Commonly, the limestone is crystalline and coarse grained, but some beds or concretions of fossiliferous dense argillaceous limestone are locally included. Near the basement highs—for example, in the vicinity of Congress Canyon—the carbonate unit is thinner and somewhat intergradational with the underlying basal clastic unit. The carbonate unit here consists mainly of thick-bedded dolomite having sand- or even grit-sized terrigenous clastic impurities and interbeds. Fossils from this unit suggest that a disconformity exists within the unit in the vicinity of John Brown Canyon and that its upper part is progressively cut out toward the Arizona basement high.

The brown calcareous sandstone unit forms the highest part of the thickened lower member in the northern part of the range and consists of massive calcareous or dolomitic siltstone and very fine grained sandstone that weathers pale reddish brown and yellowish brown. These rocks characteristically part at a high angle to the bedding and form a distinctive brown slabby talus (fig. 5) that is conspicuous at a number of places in the northern part of the range. The brown calcareous sandstone unit is nearly 300 feet thick in Congress Canyon, where interbeds and irregular patches of gray limestone form an appreciable part of its upper half, but farther away from the Arizona basement high it is mostly about 100 feet thick. Paleontologic evidence shows that most of this thinning results from interfingering of the higher parts of the brown calcareous sandstone unit into the lower part of the middle member of the Prida Formation. (See pl. 1.)

Some of the lateral variation in lithologic characters and thickness that takes place within the three successive units that form the thick lower member in the northern part of the range as they are traced toward the preexisting topographic highs on the Koipato surface have been described above. Near the basement highs, these units abruptly lose their individuality and at least locally are replaced by partly calcareous sandstone and conglomerate that laps up against the highs. On the east side of the range, this type of lateral change is well shown by the lower member in Star Canyon. Near the mouth of the canyon, the basal clastic unit, the carbonate unit, and the brown calcareous sandstone unit aggregate nearly 400 feet in thickness. Up the canyon, toward the Star-Humboldt basement high, they thin and in less than half a mile are replaced in the section near the Sheba and DeSoto mines by about 200 feet of sandstone and grit that includes, in the upper part, interbedded lenticular units of sandy limestone as much as several feet thick. Middle Anisian ammonites from the basal beds of the overlying middle member of the Prida here are like those that occur nearly 300 feet above the top of the lower member near the mouth of Star Canyon; hence, an appreciable amount of transgression evidently accompanies this lateral lithologic change. Still farther west, on the range crest between the heads of Star and Humboldt Canyons and on top of the Star-Humboldt basement high, the entire lower member consists of only a few tens of feet of Koipato-derived clastics and brown-weathering silty dolomite. As poorly preserved fossils of probable late Anisian age occur just above in the middle member, the lower member here may be wholly younger than the thick lower Prida section on the east flank of the range.

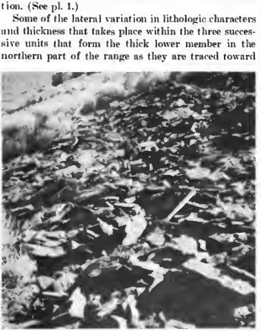


FIGURE 5.—Talus characteristic of the brown calcareous sandstone unit that locally forms the top of the lower member of the Prida Formation in the northern part of the Humboldt Range. East side of Congress Canyon near its mouth.

The lateral changes within the lower member of the Prida as it is traced from its extensive exposures on the west side of the range in Panther, Echo, and Buffalo Canyons southeastward across the range crest toward the Arizona basement high are unique in that mafic volcanic rocks are included in the sections alongside the basement high. At the head of Echo Canyon, a thick lens of metavolcanic rock fragments in a dolomitic matrix occurs within impure dolomite and limestone of the carbonate unit of the lower member, and at the head of Panther Canyon a thin flow of mafic metavolcanic rock intervenes at about this same level in the section. About 1½ miles farther south along the range crest, near "Wright Peak" (VABM 8882), vesicular mafic metavolcanic rocks form the entire upper part of the lower member, supplant the brown calcareous sandstone unit, and directly underlie the middle member of the Prida. The extrusive nature of these volcanic rocks is clearly shown by the intimate mixture of brecciated amygdaloidal volcanic fragments and brown-weathering silty dolomite like that which underlies the volcanic rocks (fig. 6). At the next exposure to the east, about 1 mile distant, at Fourth of July Flat, mafic metavolcanic

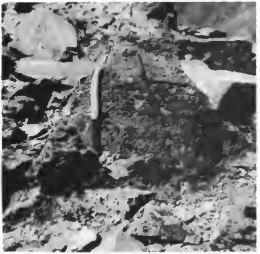


FIGURE 6.—Weathered block composed partly of vesicular and amygdaloidal mafic metavolcanic rock (lower part) and partly of impure silty dolomite (upper part). Lower member of the Prida Formation on the range crest about half a mile northwest of "Wright Peak" (VABM 8882).

rocks again form much of the lower member, but here basal clastics are absent and the volcanic unit is overlain by about 20 feet of noncalcareous grit and sandstone. The clastic unit that forms the top of the lower member can be traced eastward to the vicinity of the Arizona, Inskip, and Wheeler mines, where it becomes the basal clastic unit of a greatly thinned (total 10–30 ft) lower member consisting of basal clastic rocks overlain by impure dolomite. Thus, metavolcanic rocks in the lower member intertongue northwestward from Fourth of July Flat with a thick nonvolcanic lower member, but east of Fourth of July Flat, they abruptly lap up against the west slope of the Arizona basement high. The east slope of this basement high is marked by the rapid progressive thickening of the lower member eastward from the Arizona mine area on the spur between Jackson and Buena Vista Canyons. Both the stratigraphic relations and the paleontological evidence indicate that deposition of the lower member atop the Arizona basement high began after most or all of the thicker section of the lower member to the west, north, and northeast had already been formed.

South of Cottonwood Canyon, which limits the southward extent of the Prida outcrops in the vicinity of the Arizona group of mines, the lower part of the formation is not exposed on the east side of the range for nearly 10 miles. Unfortunately, exposures of the Prida along the west margin of the central part of the range are too deformed and altered for meaningful stratigraphic comparison. Nevertheless, the lower member of the Prida in the southern part of the range south of American Canyon is generally like that in the Arizona mine area and is probably not a temporal equivalent of the thick lower member in the more northerly parts of the range. (See pl. 2.)

In the southern part of the range, the lower member is fairly uniform from place to place and comprises basal clastics overlain by silty and sandy dolomitic and calcareous rocks. The principal lateral variations are in thickness, which ranges from about 150 feet on the east side of the range to only a few feet on the west side of Black Ridge. The basal clastic unit in the vicinity of South American and Troy Canyons is generally less than 10 feet thick, but on the south side of Fisher Canyon its thickness varies within a few hundred yards along the strike from several feet to several tens of feet. These noncalcareous clastic rocks are commonly pebbly grit of poorly rounded Koipato fragments whose white and brown colors impart a characteristic mottled appearance to fresh surfaces. Subeuhedral detrital crystals of quartz and feldspar, probably derived from a part of the Koipato such as the Weaver porphyritic rhyolite, form an appreciable part of the coarse sand grains. In places, well-stratified sandstone interlenses with these poorly sorted clastics, and the thicker sections include conglomerate of rounded pebbles up to 2 inches in diameter.

Above the basal clastic unit the greater part of the lower member in the southern part of the range is slightly silty fine-grained dolomite that is medium gray on fresh surfaces, weathers a distinctive pale yellowish brown, and locally contains nodular lenses of dark chert. These rocks tend to be massive, but in places they alternate with platy-weathering gray, pinkish-gray, or yellowish-brown silty or sandy limestone and dolomitic siltstone. An unusual occurrence in the lower member in several different fault blocks north of Troy Canyon is a several-foot-thick bed of closely packed gray limestone spheres in a brown sandy dolomitic limestone matrix. These spherical bodies, 10–20 mm in diameter, consist of an outer rim of fine-grained crystalline calcite surrounding a coarsely crystalline sparry calcite interior. Their size, shape, and composition suggest *Girvanella*-like algae whose finer structure has been obliterated by recrystallization. The highest brown-weathering dolomitic rocks of the lower member between Troy and American Canyons are distinctive in that they contain scattered granules and coarse grains of light-colored siliceous Koipato fragments. Relatively coarse grained terrigenous detritus also appears in this part of the Prida in Fisher Canyon, where coarse-grained dolomitic sandstone locally forms the top of the lower member.

MIDDLE MEMBER

The middle member of the Prida Formation, unlike the lower member, is relatively uniform in lithologic character both vertically and laterally. It thickens progressively from a few tens of feet in the southern part of the Humboldt Range to several hundred feet in the northern part of the range as a result of the inclusion of older beds at the base of the middle member northward. The Star-Humboldt and Arizona basement highs, which so profoundly influenced the character of the lower member of the Prida in the northern part of the range, also affected deposition of the middle member. Three hundred feet or more of the middle member along the east edge of the range north of Coyote Canyon was deposited before deposition of the middle member atop these basement highs commenced.

The middle member consists of laterally discontinuous thin- and medium-bedded medium- to dark-gray limestone that rarely forms units more than a few feet thick and is interbedded with calcareous silty shale and yellowish-brown or pinkish-gray very thin bedded calcareous siltstone. Locally the limestone is highly fossiliferous and formed in large part of more or less fragmentary shells of cephalopods and, in the higher parts of the section, of the pelecypod *Daonella*. In weathered surface debris, limestone float predominates, but the interbedded argillaceous and silty rocks actually form more than two-thirds of the section. Although the limestone is fine grained, it is completely recrystallized; and the molluscan shell material is coarsely crystalline, even where fossil preservation is relatively good.

Five samples of black fossiliferous limestone from the middle member in the vicinity of Fossil Hill were included in the survey of carbon and oxygen isotopic composition of limestones by Keith and Weber (1964). Three of these samples had anomalously low $C^{13}:C^{12}$ ratios in comparison with average marine limestones; the other two samples showed the same tendency to a lesser degree. Keith and Weber suggested that the relatively low C^{13} content of carbonate rocks of this kind results from deposition in an environment characterized by an abundance of decaying organic matter and restricted circulation.

A conspicuous stratigraphic marker within the middle member in the southern part of the range is a unit about 10 feet thick of massive brown-weathering medium- to thick-bedded sandy limestone. This unit, which corresponds to the *Gymnotoceras dunni* beds of the *Gymnotoceras meeki* Zone, occurs near the top of the member in the vicinity of Fossil Hill between South American and Troy Canyons, where the middle member is 150–200 feet thick, and near the middle of the thinner section of the member in Fisher Canyon. Examined microscopically, the sandy detritus can be recognized as rhyolitic debris, but partial replacement by calcite has completely obliterated the original grain boundaries, and silica has been redistributed throughout the rock in irregular patches of microcrystalline quartz which may in places replace the original carbonate.

The contact between the middle and upper members of the Prida is gradational through a few tens of feet and is marked by transition upward to darker gray regularly bedded commonly cherty carbonate rocks that generally lack argillaceous and silty interbeds. Where shearing and alteration is intense, separation of the middle and upper members is difficult; in places on the west flank of the range, no attempt was made to differentiate them on the geologic map.

UPPER MEMBER

The upper member of the Prida forms the greater part of the formation throughout the Humboldt Range. On the south wall of Fisher Canyon it is about 600 feet thick and forms about three-fourths of the entire formation. To the southwest in this same outcrop belt, both the middle and upper members thin to a combined thickness of only a few hundred feet on the west side of Black Ridge. North of Fisher Canyon the upper member increases in thickness. It is about 1,500 feet thick in Congress Canyon and may exceed 2,000 feet in thickness in the high, northern part of the range, where the upper member forms nearly half of the total pre-Tertiary outcrop area.

This disproportionate thickness of the upper member in the northern part of the Humboldt Range significantly changes the gross character of the Prida Formation from that at its type area in the East Range, and the upper member could properly be recognized as a separate formation. This is not done, however, because the lithologic distinction between the upper and middle members is commonly obscured by secondary deformation and recrystallization, and these two units are not easily differentiated in some parts of the range.

The characteristic rocks of the upper member are thin- and medium-parted, conspicuously laminated medium- to dark-gray limestone and dolomite with lenticular stringers and thin beds of dark chert (fig. 8*B*). Repetitious thin- to medium-parting units with somewhat undulating surfaces give most exposures a regularly stratified appearance (fig. 7). Interstratified with

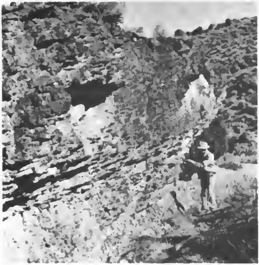


FIGURE 7.—Outcrop of dark laminated dolomite showing the thin to medium-thick, somewhat undulating parting characteristic of much of the upper member of the Prida Formation. Near east front of the range north of American Canyon.

these rocks are thick and very thick beds of massive medium- and coarse-grained organic-detrital carbonate rock that form units up to a few tens of feet thick and become increasingly abundant towards the top of the member. These massive carbonate rocks are essentially like those of the overlying Natchez Pass Formation, which is distinguished from the upper member by the absence of cherty laminated carbonate rocks.

The lamination of the regularly bedded cherty carbonate rocks results from the alternation of finely crystalline layers with very finely crystalline more carbonaceous layers. Though entirely fine grained, these rocks are wholly recrystallized. Detrital silt grains of quartz, chert, and feldspar are ubiquitous in amounts up to several percent, and wispy stringers and thin beds of yellowish brown silty carbonate rock are common in places, particularly in the southern part of the range. The distribution of calcareous and dolomitic facies in these rocks lacks any apparent regularity, and much of the dolomitization is evidently secondary, perhaps of hydrothermal origin. Scattered fine-grained dolomite euhedra indicate partial dolomitization in places, but the rocks that are entirely dolomitic have a granoblastic texture.

Chert stringers and layers constitute at least several percent of the section, and in the northern part of the range thin-bedded dark chert locally forms continuous units as much as a few tens of feet thick within the upper member. Though megascopically the boundaries between the chert bodies and the enclosing carbonate rocks are sharp, as viewed in thin section they are irregular and ragged, and both euhedra of dolomite and patches of carbonate are included within the chert. The chert is composed of microcrystalline quartz and evidently represents reconstituted layers of original siliceous organic-detrital material in some places and the replacement of original calcareous detritus in other places. Some thin chert beds in the section in Congress Canyon contain abundant outlines of sponge spicules and radiolaria, but this is unusual; similar chert beds more commonly have only a faint internal lamination with sporadic clear round spots that may have been radiolaria. Dolomite euhedra in these layers clearly replace the chert: they tend to cluster along crosscutting veinlets, and they transect the original outlines of radiolaria. In other places, particularly in the relatively thin section of the upper member in the southern part of the range, ghosts of originally calcareous pellets and shell fragments are preserved in patches and stringers of microcrystalline quartz that represent selective replacement of local concentrations of relatively coarse-grained calcareous detritus within the fine-grained laminated rocks. Some of these chert bodies accurately retain the original depositional form of these organic detrital accumulations, and the lamination of the enclosing carbonate rock is bent around them. Others were evidently infolded into the underlying carbonate layers as load casts and then truncated before burial and silicification.

Deposits of sedimentary breccia formed of somewhat rounded fragments of featureless carbonate rocks up to at least several inches in greatest dimension in a coarse clastic carbonate matrix (fig. 8.1) are a significant, though infrequent, occurrence in the upper member of the Prida. These occur as discontinuous thick units and are interpreted as submarine slide deposits. Locally their emplacement contorted and broke the underlying laminated carbonate rocks, as is shown in the specimen illustrated (fig. 8C). This specimen is from beneath the slide breccia exposed at the summit of Fossil Hill. Both the laminated carbonate and the thin chert interbeds were broken into angular fragments, implying considerable penecontemporaneous induration of these sediments. Some other isolated occurrences of contorted bedding in the upper Prida are probably also the result of submarine sliding and slumping, but in the northern part of the range these are difficult to distinguish from the effects of the more general tectonic deformation.

Discontinuous units of altered volcanic rocks form a minor part of the upper member in the northern part of the range. Some of these rocks are obviously extrusive, whereas others probably represent feeder dikes. Near Star Peak, amygdaloidal flow rocks and volcanic breccia locally form the highest part of the upper member and directly underlie the Natchez Pass Formation. Similar mafic metavolcanic rocks appear at places on the west flank of the range from Echo Canyon northward at about the same stratigraphic level high in the upper member of the Prida Formation. The thickest and most extensive of these volcanic units is exposed intermittently for about 2 miles between Humboldt and Prince Royal Canyons in an eastward-plunging overturned syncline beneath the Humbolt City thrust. On the north wall of Humboldt Canyon this unit exceeds 200 feet in thickness and locally includes pillowlike structures up to several feet in size embedded in a limy tuffaceous matrix that contains poorly preserved marine fossils. The mafic igneous rocks that forms a large outcrop on the range crest about 2 miles north of Star Peak is evidently an altered diabase now composed largely of plagioclase and chlorite. Its contact cuts across the bedding of the Prida at a low angle, and it is considered to be a dike related to the extrusive rocks in the Prida or in higher parts of the Star Peak Group.

FOSSILS AND AGE

The age of the Prida Formation in the Humboldt Range is well established by ammonite and halobiid pelecypod faunas. (See fig. 3.) Locally, in the northern part of the range where its thickness and time span are greatest, the Prida ranges from late Early Triassic to early Late Triassic in age; farther south, where its deposition began later and where its upper part is supplanted by massive carbonate rocks of the Natchez Pass Formation, the Prida is wholly of Middle Triassic age.

In the lower member of the Prida Formation along the northeast flank of the range between John Brown and Santa Clara Canyons, where this member is thickest, most calcareous, and not too badly sheared and recrystallized, at least two distinct successive ammonite faunas occur. The older of these is termed the *Subcolumbites* fauna, and the younger fauna is that of the *Neopopanoceras haugi* Zone. The composition and stratigraphic occurrence of these faunas, as well as those from the overlying lower parts of the middle member, are shown in table 1 and on plate 1.

The older fauna from the lower member is best represented by collections made from limestone concretions that occur at a consistent stratigraphic level about 50 feet above the basal clastics at USGS Mesozoic locality M2360 and along strike for several hundred feet between Coyote and Bloody Canyons. The presence of *Subcolumbites* and species of *Prohungarites* place this fauna near the top of the Lower Triassic and relatively high in the Spathian Stage, the youngest of the four Lower Triassic stages recently introduced by Tozer (1965b, 1967). Among float collection made nearby from USGS Mesozoic locality M1688, the *Prohungarites* referred to in table 1 as *P.* n. sp. "B" is probably from a stratigraphic level only slightly above that of locality M2360. It is like the species of *Prohungarites* characteristic of the "*Prohungarites* beds" at Hammond Creek, Bear Lake Valley, southeastern Idaho (Bernard Kummel, written commun., 1965), the fauna of which has been listed by Kummel (1954, p. 187). The *Subcolumbites* beds of northwestern Nevada and the *Prohungarites* beds of southeastern Idaho are therefore regarded as approximate temporal equivalents by Silberling and Tozer (1968).

Of significance for reconstructing the depositional history of the lower Mesozoic rocks of northwestern Nevada is the fact that ammonite species such as *Prohungarites* sp. "B", *Zenoites*? sp. "A", and *Subcolumbites* sp. "A", which occur in the oldest parts of the Prida Formation, also occur a few tens of feet above the base of the Tobin Formation at USGS Mesozoic locality M2565 near the south end of the Tobin Range. Hence, locally, as in the northern Humboldt Range, the Prida Formation at the base of the "Winnemucca sequence" of lower Mesozoic strata includes beds as old as the Tobin Formation at the base of the "Augusta sequence," contrary to the view previously held by Silberling and Roberts (1962, p. 37). Another fauna from about the same stratigraphic position in the Tobin Formation of the Tobin Range, but from a locality about 2 miles farther south, is currently being described by Prof. Bernard Kummel. Though this fauna lacks *Prohungarites* and contains a different species of *Subcolumbites*, it is otherwise generally similar in composition and is probably not much different in age.

The *Neopopanoceras haugi* fauna, represented especially by "*Hungarites*" *yatesi* and distinctive species of parananitids, has been found in the lower member of the Prida Formation at several places along the northeast flank of the Humboldt Range from Bloody Canyon south to the south side of Coyote Canyon. It occupies a consistent stratigraphic level within a few tens of feet below the brown calcareous sandstone unit that forms the highest part of the lower member in this part of the range. Hence, although it has not been found directly above the *Subcolumbites* fauna, its position in the section between Coyote and Bloody Canyons, where the carbonate unit of the lower member is thickest, is about

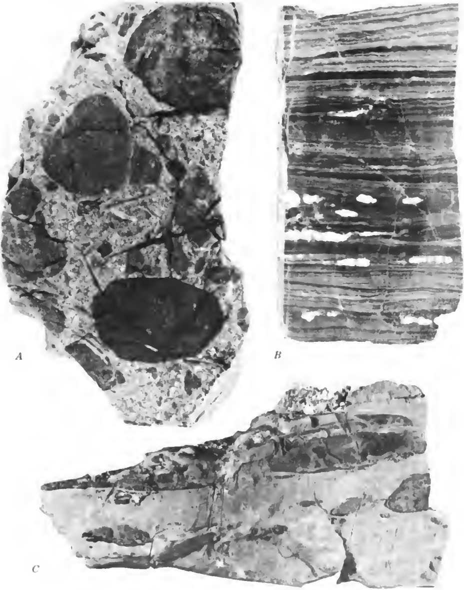

A
B
C

TABLE 1.—*Composition and biostratigraphic assignment of the ammonite faunas from the lower part of the Prida Formation in the northeastern part of the Humboldt Range*

[Location of USGS Mesozoic localities shown on pl. 1. X, occurrence of species; ?, uncertain occurrence]

	ANISIAN STAGE																		SPATHIAN STAGE							
	Anagymnotoceras varium Zone											*Lenotropites caurus* Zone							*Neopopanoceras haugi* Zone					*Subcolumbites* beds		
	M970	M2839	M2822	M2821	M2819	M2369	M2359	M2830	M2826	M2838	M980	M2367	M2358	M2828	M2362 (float)	M2364	M2363	Brown calcareous sandstone unit	M2827	M2824	M2831 (float)	M2834	M2823	M1665 (float)	M1164	M2360
Pseudodanubites? haldi (Mojsisovics)	X	X	X																							
Anagymnotoceras aff. *A. moderatum* McLearn		?	X																							
Ismidites aff. *I. marmarensis* Arthaber	X						?																			
Czekanowskites hayesi (McLearn)	X																									
Longobardites nevadanus Hyatt and Smith		?					?	?																		
L. cf. *L. lawsoni* McLearn				?	?					X	?															
Acrochordiceras hyatti Meek	?	?	?		X	X			X	?																
Gymnites perplanus (Meek)	?	?							?																	
Cuccoceras bonaevistae Hyatt and Smith				?	?	X	X	X		X	X															
Hollandites sp.										?	X															
Dagnoceratid n. gen., n. sp. A							X	?			X															
Isculites n. sp.				?	?		X																			
Lenotropites caurus McLearn												X	X	X	X											
Acrochordiceras aff. *A. americanum* McLearn												X	X	?	?											
Isculites meeki (Hyatt and Smith)												X	X													
Leiophyllites? sp. A												X	X													
Eophyllites sp. A															?	X	?									
Neopopanoceras haugi (Hyatt and Smith)																						X				
Acrochordiceras cf. *A. inyoense* Smith																						X				
"*Xenodiscus*" *bittneri* Hyatt and Smith																						X				
"*Hungarites*" *yatesi* Hyatt and Smith																			X	X	X	X	X			
"*Tirolites*" *pacificus* Hyatt and Smith																						X				
Metadagnoceras n. sp. ex aff. *M. pulcher* Tozer																						X	X	?		
Isculitoides? sp. A																					X	X	X			
Paranannitid sp. B																			X	X	X		X			
Prohungarites n. sp. A																					X			X		
P. n. sp. B																								X		
Zenoites? sp. A																					X			X		
Prohungarites cf. *P. similis* Spath																										X
P. cf. *P. tuberculatus* (Welter)																								?		X
Nordophiceras? sp.																									X	
Subcolumbites n. sp. A																									X	X
Stacheites cf. *S. prionoides* Kittl																									?	X
Ussurites? sp.																										X
Isculitoides sp.																										X
Arnautoceltites sp.																									X	X

200 feet higher than that of the *Subcolumbites* beds such as those at locality M2360.

South of Coyote Canyon, where the carbonate unit is much thinner, the relative superposition of the *Neopopanoceras haugi* and *Subcolumbites* faunas is obscure. In John Brown Canyon the stratigraphic position of the *N. haugi* Zone, which can be recognized as far southwest as USGS Mesozoic locality M2823 near the mouth of this canyon, is apparently occupied instead by *Subcolumbites* beds, as at USGS Mesozoic locality M1164. To explain this, a disconformity within the carbonate unit here is postulated on plate 1. In support of this interpretation, the beds that would be separated by this disconformity are quite different in composition; the carbonate unit at locality M1164 is composed of coarse-grained organic-detrital sandy limestone, whereas the *Neopopanoceras haugi* Zone a short distance farther northeast consists of well-bedded dense argillaceous gray limestone. Moreover, locality M1164 is near the depositional margin of these rocks of the lower member where they lap up against the Arizona basement high, and gaps in the section might be expected here.

Heretofore, the only known occurrence of the *Neopopanoceras haugi* fauna was in the Inyo Mountains of southeastern California, where it is not in close strat-

FIGURE 8.—Carbonate rocks from the upper member of the Prida Formation on Fossil Hill, in the southeastern part of the range. All figures natural size. *A*, Dolomite sedimentary breccia from thick discontinuous unit interpreted as a submarine slide deposit within the laminated thin-bedded limestone and dolomite of the upper member. *B*, Laminated dolomitic limestone like that which forms most of the upper member. Sawn slab photographed in liquid to heighten contrast between laminae. White patches are void fillings of sparry calcite and quartz. Stratigraphic orientation of hand specimen uncertain. *C*, Weathered surface of brecciated and recemented very thinly interbedded laminated dolomite (light colored) and chert (dark colored). Disruption of bedding attributed to emplacement of carbonate slide deposit that directly overlies these rocks in the section.

igraphic succession with other faunas. In the absence of an adequate means of dating this unique assemblage, its age has been customarily regarded as earliest Middle Triassic (Smith, 1914, p. 5–6; Spath, 1934, p. 35; Arkell and others, 1957, p. L124). Collections from the *N. haugi* Zone at USGS Mesozoic locality M2834 near the edge of the Humboldt Range just south of Coyote Canyon include most, and perhaps all, of the ammonites originally ascribed to it in the Inyo Mountains by Smith (1914) plus a few additional kinds. (See table 1.) Compared with the faunal succession found elsewhere in North America, the relative position of this fauna in the Humboldt Range with respect to the lower Anisian "*Longobardites*" *caurus* Zone indicates that the *N. haugi* Zone is approximately equivalent to the uppermost Lower Triassic *Kyserlingites subrobustus* Zone of arctic regions (Silberling and Tozer, 1968). A further reason for considering the *N. haugi* Zone as highest Lower, rather than lowest Middle Triassic is the recent discovery of poorly preserved ammonites probably belonging to the uppermost Lower Triassic genus *Keyserlingites* several tens of feet stratigraphically above the *N. haugi* beds in the Inyo Mountains. "*Keyserlingites*? sp. indet." is, in fact, listed by Smith (1914, p. 6) from the *N. haugi* Zone of the Inyo Mountains, but this identification cannot be confirmed.

The middle member of the Prida Formation in the Humboldt Range includes perhaps the most complete succession of Anisian ammonite faunas known anywhere in the world. These faunas have been partly described by Gabb (1864), Meek (1877), and Hyatt and Smith (1905), and they formed the basis for Smith's monographic treatment of the Middle Triassic marine invertebrate faunas of North America (Smith, 1914). These previous authors, however, gave little or no attention to the stratigraphic distribution of these faunas. The research described here and in another paper being prepared by Silberling demonstrates the existence of as many as 15 distinct, stratigraphically successive, Anisian ammonite faunas in the middle member of the Humboldt Range. In terms of biostratigraphic units that are more or less coordinate in rank with those recognized elsewhere in the Triassic of North America, the beds characterized by these faunas are grouped into five successive ammonite zones.

Lower and middle Anisian faunas are represented only in the northern parts of the range, where the middle member is thickest and has its greatest age span. Unfortunately, the preservation of fossils here is for the most part poor. Owing to the generally transgressive nature of the Prida southward in the range, none of the middle member is as old as early or middle Anisian in the southern parts parts of the range. Upper Anisian ammonite faunas occur in the middle member throughout the range, but they are best developed in the southeast part of the range at localities such as the classic collecting site at Fossil Hill.

The Anisian faunas of the Humboldt Range are dominated by cephalopods and by planktonic or probable pseudoplanktonic pelecypods: *Posidonia*-like forms and "*Sphaera*" *whitneyi* Meek are prevalent in the middle Anisian whereas species of *Daonella* and "*Rhynchopterus*" *obesus* Gabb are well represented in the upper Anisian. With few exceptions, brachiopods and gastropods are scarce, and other kinds of larger marine invertebrate fossils are unkown.

Where the lower and middle members of the Prida are thickest, in the northeastern part of the range, fossils have been found at several places in the basal beds of the middle member just above the brown calcareous sandstone unit that forms the top of the lower member. In the vicinity of Star Canyon, as at USGS Mesozoic locality M2364, an abundance of the ammonite *Eophyllites* sp. "A" and the brachiopod *Spirigera* cf. *S. stoliczkai* Bittner locally characterizes the lowermost few tens of feet of the middle member. No refined age significance can be attributed to these fossils, however, and the ammonites found at other localities from the same stratigraphic level, though exhibiting appreciable variety, are wholly indeterminate.

In the same general area—for example, at USGS Mesozoic localities M2358 and M2828—a discrete ammonite fauna characterized by *Isculites meeki* (Hyatt and Smith) and *Lenotropites caurus* (McLearn) occurs 100–150 feet above the base of the middle member. The presence of the latter species and of associated specimens of *Acrochordiceras*, which are closer to *A. americanum* McLearn than to any other described species, indicates that this part of the section is in the *L. caurus* Zone, which is typical of northeastern British Columbia and is the oldest zone recognized in the Anisian of North America (Silberling and Tozer, 1968; Tozer, 1967).

The next higher ammonite zone, to which the Canadian name *Anagymnotoceras varium* Zone (Silberling and Tozer, 1968) is applicable, is as much as 150 feet thick; it is distinguished by the best developed and most widely distributed ammonite fauna found in the Prida Formation in the northern part of the Humboldt Range. In those places where the Prida laps onto topographic highs on the preexisting Koipato surface, the *A. varium* Zone may occur immediately above whatever rocks locally constitute the lower member. Away from such basement highs, as along the east front of the range north of Coyote Canyon, the lowest fossils of the *A. varium* Zone are found up to 300 feet above the base of the middle member and are 100–125 feet above the fossiliferous beds of the *L. caurus* Zone.

In addition to the occurrences of *A. varium* Zone fossils shown on plate 1, other significant localities at which cephalopods of this zone occur are USGS Mesozoic localities M533, M969, M1180, M1181, and M1875 on the east side of the range north of Unionville.

Some ammonite species characteristic of the *A. varium* Zone in the Humboldt Range (table 1), such as *Acrochordiceras hyatti* Meek (not Smith and other authors) and perhaps *Gymnites perplanus* Meek, range through the zone; others are more stratigraphically restricted within the zone. *Cuccoceras bonaevistae* Hyatt and Smith, *Longobardites* cf. *L. larvalis* McLearn, and *Isculites* n. sp. are evidently confined to the lower part of the zone, whereas *Pseudodanubites? halli* (Mojsisovics), *Longobardites nevadanus* Hyatt and Smith, and *Czekanowskites hayesi* (McLearn) have been found in its higher parts only.

The *Anagymnotoceras varium* Zone is assigned to the middle Anisian as recognized in North America by Silberling and Tozer (1968). It is regarded as older than the middle Anisian *Balatonites shoshonensis* Zone, the other North American ammonite zone assigned by Silberling and Tozer to the middle Anisian, but the two zones have not been found in stratigraphic sequence. Up to the present time the *B. shoshonensis* Zone has been found only in the Favret Formation, which crops out in the Augusta Mountains and adjacent parts of northwestern Nevada southeast of the Humboldt Range. Some genera such as *Acrochordiceras* and *Longobardites* occur in both zones but are represented in the *B. shoshonensis* Zone by species that appear to be more advanced morphologically than those in the *A. varium* Zone, and some genera such as *Proarcestes* and *Ptychites*, that range up into younger strata are found in the *B. shoshonensis* Zone but not in the *A. varium* Zone. The 150 feet or so of the unfossiliferous beds that separate the *A. varium* Zone from the upper Anisian *Gymnotoceras rotelliformis* Zone in the northern Humboldt Range leave ample room in the section for middle Anisian strata correlative with the *B. shoshonensis* Zone.

Upper Anisian ammonite and *Daonella* faunas are widely distributed in the uppermost 100 feet of the middle member of the Prida Formation in the Humboldt Range, although nowhere are they as completely developed and as well preserved as in the vicinity of Fossil Hill between Troy and South American Canyons. The upper Anisian section here is the type locality for the *Gymnotoceras rotelliformis*, *Gymnotoceras meeki*, and *Gymnotoceras occidentalis* Zones of Silberling and Tozer (1968), which heretofore have been lumped informally into an all-inclusive "*Gymnotoceras* zone" (Silberling, 1962, p. 153). These faunas were monographed by Smith (1914), who treated them as a single, stratigraphically equivalent assemblage. The preliminary revision of their taxonomy and stratigraphic distribution by Silberling (1962) now requires some modifications, the most important of which are (1) the recognition of *Gymnotoceras rotelliformis* as a distinct species occurring below, but intergrading with, *G. blakei;* (2) the inversion of the *Paraceratites clarkei* and *P. vogdesi* beds and the recognition of a still older level, the *P. burckhardti* beds; (3) the combination of *Gymnotoceras washburnei* and *G. occidentalis*, as first revised, under *G. occidentalis;* and (4) the transfer of "*Anolcites*" *furlongi* and "*A.*" *gabbi* to the genus *Nevadites*.

Incorporating these changes, the sequence of upper Anisian faunal units recognized in the Fossil Hill area, listed from youngest to oldest, and their grouping into zones, is as follows:

Gymnotoceras occidentalis Zone
  Nevadites gabbi beds
  Nevadites furlongi beds
  Nevadites humboldtensis beds
  Nevadites hyatti beds
Gymnotoceras meeki Zone
  Gymnotoceras dunni beds
  Gymnotoceras meeki beds
  Gymnotoceras (*Frechites*) *nevadanus* beds
Gymnotoceras rotelliformis Zone
  Gymnotoceras blakei beds
  Paraceratites cricki beds
  Paraceratites vogdesi beds
  Paraceratites clarkei beds
  Paraceratites burckhardti beds

Some faunal resemblance exists between the *G. rotelliformis* and *G. meeki* Zones and the typical upper Anisian of Alpine Europe. The *G. occidentalis* Zone, however, is regarded as upper Anisian rather than lower Ladinian because the typically Ladinian ammonite genus *Protrachyceras* makes its first appearance in the next higher, *Protrachyceras subasperum* Zone in the lowest beds of the upper member of the Prida.

Although larger marine invertebrate fossils other than cephalopods and a few kinds of pelecypods are either scarce or absent in the middle member of the Prida, some other kinds of fossils do occur. Skeletal remains of ichthyosaurian reptiles are fairly common, particularly in the beds containing the greatest concentration of ammonite shells. The specimens of ichthyosaurs, including one nearly complete skeleton, described by Merriam (1908), are from the upper Anisian in the vicinity of Fossil Hill. Fish teeth and spines, presumably from localities in the middle member, have been described respectively by Wemple (1906) and Davidson (1919). Mosher and Clark (1965) reported that conodonts are abundant in the *Gymnotoceras rotelliformis*, *meeki*, and *occidentalis* Zones in the vicinity of Fossil Hill and that the same assemblage of species, which is like that known from the Anisian of Europe, apparently ranges through all three zones.

The top of the *G. occidentalis* Zone roughly coincides with the lithic transition between the middle and upper members of the Prida Formation throughout the Humboldt Range. In the vicinity of Fossil Hill and at a few other places, as in the Arizona mine area, the lowermost few tens of feet of the upper member are characterized by primitive species of *Protrachyceras* such as *P. subasperum*, and by *Daonella* aff. *D. taramellii*. These beds are termed the *Protrachyceras subasperum* Zone and are regarded as earliest Ladinian in age (Silberling and Tozer, 1968).

Except for the *P. subasperum* Zone at its base, the upper member of the Prida is poorly fossiliferous; throughout most of the member the only fossils found are scattered specimens of trachyceratid ammonites that are mostly flattened, silicified, and generally indeterminate. In the higher parts of the upper member, however, pelecypods closely similar to, or identical with, *Daonella lommeli* Wissman, an index fossil of the Alpine upper Ladinian (uppermost Middle Triassic), have been found at several places. In Fisher Canyon (USGS Mesozoic loc. M3095) in the southern part of the range, these pelecypods and an additional undescribed species of *Daonella* occur about 50 feet below the top of the Prida. In Congress Canyon (USGS Mesozoic loc. M907), *D.* cf. *D. lommeli* was found with a few poorly preserved ammonites of the long-ranging genera *Protrachyceras?*, *Proarcestes*, and *Hungarites* about 600 feet below the top of the upper member at about the level where thick interbeds of massive carbonate rocks become conspicuous within the Prida section. And at the northeastern tip of the range, west of Nevada State Highway 50 (USGS Mesozoic loc. M1689), *Daonella* cf. *D. lommeli* again occurs in the upper member of the Prida within a few tens of feet below the base of the overlying Natchez Pass Formation. Although this species may have an appreciable stratigraphic range, this variation in the amount of Prida section above its occurrence in different places (pl. 2) is great enough to indicate that the upper limit of the Prida is somewhat younger in the north-central part of the Humboldt Range than it is in the southern and the northeastern extremities of the range.

The youngest fossils in the upper member of the Prida are poorly preserved ammonites from impure limestone beds associated with thin units of mafic volcanic rock high in the section in the northwestern part of the Humboldt Range. The best of these faunas was found about half a mile north of the Standard mine (USGS Mesozoic loc. M1186) and includes *Sageceras* and *Proarcestes* along with trachyceratid and clionitid ammonites. Unfortunately, the trachyceratids cannot be positively identified, but their advanced sculpture strongly suggests assignment to *Trachyceras* s.s., which is indicative of an early Karnian age. An age at least this young is substantiated by their association with clionitids; a still younger age is unlikely because the genus *Sageceras* is not known above the lower Karnian.

NATCHEZ PASS FORMATION

The upper part of the Star Peak Group in the Humboldt Range is the Natchez Pass Formation named from exposures at Natchez Pass in the East Range. Massive carbonate rocks characterize the Natchez Pass Formation, but subordinate units of mafic volcanic rocks, terrigenous elastic rocks, and impure limestones permit its subdivision into local members and map units. The lower age limit of the Natchez Pass varies from late Ladinian in the southern part of the Humboldt Range to early Karnian in the northwestern part of the range; the upper age limit is poorly controlled but is probably late Karnian throughout the range. (See fig. 3.)

Exposures of the Natchez Pass are widely scattered in the Humboldt Range, and only those at the south end and at the northeastern tip of the range preserve a complete section of the formation. In the southern part of the range the Natchez Pass swings across Black Ridge in a broad outcrop band that forms the south flank and summit of Buffalo Mountain, and scattered outcrops then continue northward along the southeast front of the range to Indian Creek Canyon north of Fitting. To the north, on the west side of the range a nearly complete section of the Natchez Pass forms a belt paralleling the range front from Panther Canyon north to the Standard mine area, where the Natchez Pass forms the upper plate of the Standard thrust. Structurally below the Standard thrust, the upper part of the Natchez Pass then forms the sole of the Humboldt City thrust and continues northward in a narrow continuous band beneath the Grass Valley Formation along the western foothills of the range to a point north of Humboldt Canyon. In the high, northern part of the Humboldt Range incomplete sections of the Natchez Pass form the imposing limestone cliffs at the head of Congress Canyon, the crest of the range in the vicinity of Star Peak, and the summit of the 9,275-foot peak (Santa Clara Peak) about 2½ miles north of Star Peak. And finally, the Natchez Pass underlies most of the Mill City hills, the line of the hills projecting northeastward from the north end of the Humboldt Range. (See fig. 1.)

In most of the Humboldt Range, the Natchez Pass Formation is divided into two readily distinguished informal members. The lower member consists of cliff-forming massive carbonate rocks that in the southern part of the range interfinger with mafic volcanic rocks. An abrupt change to nonresistant impure limestone marks the base of the upper member, the higher parts of which are again composed of massive pure carbonate rocks like those of the lower member. The slope-forming impure limestone in the lower part of the upper member in the northern part of the main range includes subordinate amounts of both volcanic and terrigenous clastic rocks not represented in the equivalent part of the section farther south. Otherwise, this distinctive unit is very much the same in both parts of the range. These members are not recognized in the structurally contorted, but probably complete, section in the Mill City hills, though a thick unit of terrigenous clastic rocks, not represented elsewhere in the range, divides the recrystallized carbonate rocks of the Natchez Pass Formation here into two parts of about equal thickness.

The relative proportion of limestone and dolomite is variable among the carbonate rocks of the Natchez Pass Formation. In general the sections in the southeast and northeast extremities of the range are more dolomitic than those in the northern part of the main range, but nowhere does dolomite predominate over limestone through appreciable thicknesses of section. In its present form, much of the dolomite in these rocks is evidently a secondary replacement of limestone and commonly occurs as coarsely crystalline masses in areas of shearing or fracturing. However, some finely and medium-crystalline gray massive carbonate beds are also partly or wholly dolomitic and may have been primarily enriched in magnesium.

The total thickness of the Natchez Pass Formation in the southern part of the Humboldt Range is about 2,500 feet, the lower 1,500 feet of which represents the massive carbonate rocks and included volcanic rocks of the lower member (pl. 2). To the north, the lower member progressively thins to only several hundred feet by regressive interfingering with the underlying Prida Formation, and, assuming an approximately constant thickness for the upper member, the total thickness of the Natchez Pass in the northwestern and high, northern parts of the range may be only about half that 20 miles or so farther south. From the high, northern part of the range northeastward to the Mill City hills, the formation thickens again at the expense of the underlying Prida Formation to about 2,000 feet. This estimated thickness, however, is only a rough approximation because of the deformation of the largely overturned section here.

Wherever exposed, the contact between the massive carbonate rocks that form the highest part of the Natchez Pass and the metapelitic rocks of the overlying Grass Valley Formation is abrupt; the two rock types are not interlayered, and the transition between them takes place within a few feet. In most places the sharpness of the contact between these two rock units with different styles of deformation has been heightened by local shearing.

LITHOLOGIC DESCRIPTION

As the lithologic units that make up the Natchez Pass Formation are not the same throughout the Humboldt Range owing to lateral variations, the formation is best described as a whole in each of its principal outcrop areas rather than in terms of its various lithologic subdivisions.

In the southern part of the range, the Natchez Pass is readily divided into two members: a lower member of massive carbonate rocks that complexly intertongue with mafic volcanic rocks and locally include very subordinate amounts of terrigenous detritus, and an upper member that is wholly calcareous. The southwesternmost exposures of the lower member on the west side of Black Ridge overlooking Packard Flat are predominantly volcanic flows and breccia in several units of varying thickness interspersed with limestone units. The aggregate thickness is about 1,500 feet. Eastward across Black Ridge, massive carbonate rocks form an increasingly large part of the section, and from Cow Canyon northward along the southeastern margin of the range, they form nearly all of the member, which gradually thins to about 1,000 feet north of American Canyon. From Cow Canyon northward, volcanic rocks are restricted to the highest part of the lower member and form a laterally persistent unit several tens of feet to a few hundred feet thick separating the thick section of massive carbonates below from the impure limestone of the basal part of the upper member above.

The carbonate rocks of the lower member, where not mixed with volcanic rocks are a monotonous succession of medium-gray, thick and very thick bedded limestone and dolomite, all of which is recrystallized, somewhat broken, and pervasively veined with calcite. Massive dolomite beds are generally subordinate except near the base of the section in the vicinity of American Canyon, where they are a major constituent. Some sugary masses of light-colored crystalline dolomite crosscut bedding and evidently follow zones of fracturing. Secondary recrystallization has largely obliterated the original texture of these rocks, but enough shelly and echinodermal debris are commonly discernible to suggest that it formed an organic-detrital framework which may have been originally filled with sparry calcite matrix. Both shell fragments and matrix are now medium to coarsely crystalline. Large isolated fragments of recrystallized *Thecosmilia*-like phaceloid corals were noted in several places between Fisher and Cow Canyons, and poorly preserved silicified molluscan and brachiopod shells are not uncommon.

In the fault blocks of the Natchez Pass north of American Canyon, a bed several feet thick of well-rounded chert granules and pebbles occurs within the massive limestone and dolomite of the lower member about 400 feet above its base and forms a useful local stratigraphic marker. This bed is crudely stratified owing to wisplike variations in the packing density of the chert clasts; these clasts may be tightly packed with siliceous cement or sporadically scattered in coarse-grained organic-detrital limestone.

Another siliceous detrital unit is associated, oddly enough, with the mainly volcanic section of the lower member in the vicinity of South Relief Canyon. This unit, which is about 20 feet thick and can be traced laterally for about 1 mile in the upper part of the member, resembles in the field some of the dark sheared volcanic tuffs at other levels in the section. In thin section, however, it is seen to be composed largely of quartzose silt to which the dark color is imparted by interstitial material that may be tuffaceous in origin.

The mafic volcanic rocks in the lower member of the Natchez Pass Formation in the southern part of the range are a heterogeneous assemblage of dense or amygdaloidal nonporphyritic massive flows, breccias, and tuffs, in part intimately mixed with impure organic-detrital limestone. The flow rocks and breccia clasts are mainly yellowish brown or greenish gray and are completely altered. The plagioclase laths of the groundmass are either albitic or ghosted by calcite and sericitic material and are mixed intergranularly with chlorite, calcite, epidote-group minerals, ferric oxides, and much fine-grained "dust." No original mafic minerals are preserved in the several specimens examined petrographically. Amygdules, where present, commonly show a regular zoning. An outer rim of scattered opaque grains is bordered interiorly by microcrystalline quartz or chlorite which, in turn, borders a central filling of coarse calcite or quartz crystals. A primary volcanic origin for at least some of the breccias associated with the flow rocks is shown in thin section by devitrified, but clearly defined, glassy rims on the breccia clasts.

Stratigraphic unity is provided the laterally variable and somewhat heterogeneous lower member of the Natchez Pass by the overlying upper member, which is wholly calcareous and is constant in lithologic character throughout the southern part of the range. The lower part of the upper member is yellowish-brown and gray mostly thin- and medium-bedded limestone that forms smooth, evenly stratified brown slopes; it contrasts sharply with the upper part of the member, which is cliff-forming thick to very thick bedded massive gray limestone resembling that of the lower member. Each of these parts of the upper member is about 500 feet thick, and though the upward change from one to the other is completely gradational, they can be mapped separately. The well-bedded brown-weathering impure limestone in the lower part of the upper member differs markedly in texture from the medium or coarsely crystalline organic-detrital massive carbonate rocks that form the bulk of the Natchez Pass in most places. This impure limestone consists of partly broken pelecypod, brachiopod, and gastropod shells that have been replaced by medium-grained mosaics of calcite and are sparsely to tightly packed in a very finely crystalline calcite groundmass which could be either an original calcilutite or a micrite whose recrystallization was perhaps arrested at a very fine grain size by clay-size terrigenous impurities. The more coarsely crystalline components of the limestone, such as the molluscan and brachiopod shells and the fillings of shell interiors and fractures, commonly have a conspicuous yellowish-orange limonitic stain that contrasts strongly with the olive gray or medium gray of the matrix. The nature and amount of noncarbonate impurity in these rocks are shown by chemical analyses of two characteristic samples—one from Cow Canyon and another from American Canyon. Their Al_2O_3 content of about 1.5 percent provides an index of the amount of clay; Fe_2O_3 values are near 0.7 percent. SiO_2 amounts to about 6 percent, part of which may represent quartz silt, although secondary microcrystalline quartz is more conspicuous in thin section. For comparison, the combined amounts of Al_2O_3, Fe_2O_3, and SiO_2 in analyzed samples of massive gray limestone from the lower member of the Natchez Pass averages only a little over 0.1 percent. The calcitic nature of the impure carbonate rocks in the lower part of the upper member is indicated by the relatively low MgO content of 0.5–0.6 percent of the two analyzed samples.

The section of the Natchez Pass Formation represented by scattered and incomplete exposures in the northwestern and high, northern parts of the Humboldt Range is generally similar to that in the southern part of the range. Two members of the formation that seem to correspond to those established farther south in the range are recognized. The lower member, however, is composed entirely of massive carbonate rock and thereby differs from the lower member in the southern part of the range because it lacks volcanic and terrigenous clastic units and is much thinner. Above the highest beds of dark laminated cherty limestone included in the Prida Formation, the massive carbonate rocks that constitute the lower member of the Natchez Pass thin to only a few hundred feet in their northwesternmost exposures. The very thick bedded, or even unbedded, character of the lower Natchez Pass results in prominent cliff-forming exposures that commonly exhibit cavernous weathering.

Where the lower member forms the prominent cliffs at the head of Congress Canyon, it is essentially a single bed about 600 feet thick that dips gently westward. The lower member is also represented in the cliffs on the east flank of Star Peak (fig. 4), which from a distance might be mistaken as the northward extension of the clifflike exposure in Congress Canyon. Actually, the two exposures are in different structural blocks; moreover, the steep face of the Star Peak cliffs, instead of exposing a section of the lower member, roughly parallels the bedding of steeply inclined Natchez Pass and Prida strata that have been bent sharply downward from the equivalent nearly flat lying beds exposed above the cliffs on Star Peak. This abrupt downfold is thought to have resulted from eastward overriding on the Tehama reverse fault, which is present at depth but is truncated by the younger, Santa Clara and American basin normal faults, whose traces merge along the foot of the cliffs. Above these cliffs, the relatively undisturbed lower member of the Natchez Pass on Star Peak is about 400 feet thick and forms conspicuous massive outcrops that encircle the summit of Star Peak and the high range crest to the southwest. Farther north, similar cliffy exposures of the lower member form the summit of Santa Clara peak and cap the ridge to the north on the west side of the Santa Clara fault. In the superficially similar belt of craggy outcrops along the trace of the Tehama fault, however, the rock is a tectonic breccia formed largely of material from the upper member of the Prida Formation, though it may include some material from the Natchez Pass toward the north end of this fault zone, where it passes under the alluvial fill of the Humboldt River valley.

Along the west front of the range, between Panther and Buffalo Canyons and west of the Eldorado fault, the lower member of the Natchez Pass Formation is again distinguished by its conspicuous massive character and contrasts with the more thinly bedded and more easily eroded adjacent parts of the Star Peak Group. In this outcrop belt, the thickness of the lower member is as little as 200 feet, a minimum for the exposures of this unit in the Humboldt Range.

The composition of the lower member of the Natchez Pass in the northwestern and high, northern parts of the Humboldt Range is mainly limestone; unlike in the exposures farther south in the range, dolomite is not present in sufficient amounts to be readily recognized in the field. The limestone is massive and homogeneous throughout. It weathers a medium gray, but in most places it is much broken and intricately veined with white calcite. Weathering of this vein material commonly imparts a red stain to the outcrops. Viewed microscopically, the limestone is featureless and has a medium- to coarse-grained granoblastic texture. On weathered or sawn surfaces, however, patches of crystalline white calcite can in some places be recognized as recrystallized coarse-grained shell fragments and echinodermal debris. "Rapid rock" chemical analyses of samples from three different levels within the lower member on the ridge north of Panther Canyon indicate the high degree of purity of this carbonate rock. Combined percentages of CaO, MgO, and CO_2 range from 98.7 to 99.3 percent. The MgO content for two of these samples is less than 1 percent; for the other sample, in which clusters of secondary dolomite euhedra are evident in thin section, it is 4.3 percent. The principal noncarbonate components are silica and water.

The upper member of the Natchez Pass Formation is only partly represented in the northern part of the main range. Incomplete sections of its lower part overlie the massive limestones of the lower member in three places: along the edge of the range from Panther Canyon north to the Standard mine area, at the head of Congress Canyon, and at Star Peak and southwestward for about 2 miles along the crest of the range. Like the lower part of the upper member in the southern Humboldt Range, these rocks are mainly relatively impure and nonresistant limestone that is evenly stratified, thin to thick bedded, and brown weathering. In the higher parts of the range they tend to form poor outcrops and smooth soil-covered slopes. The most complete section forms the summit of Star Peak, where about 500 feet of impure limestone describes a shallow synclinal fold and grades upward into about 100 feet of massive thick-bedded gray limestone that caps the highest part of the peak. This transition from nonresistant impure limestone upward into massive gray limestone presumably corresponds to that which takes place within the upper Natchez Pass in the southern part of the range. If so, the thickness of the impure limestone unit that forms the lower part of the upper member is about the same in both parts of the range, as shown on plate 2.

The impure limestone that forms most of the lower part of the upper member in the northern part of the range is closely similar in texture and composition to the corresponding part of the section farther south. On fresh surfaces it is medium gray or olive gray with irregular streaks and mottles of yellowish brown. Bivalve and gastropod shell fragments, along with echinodermal debris, commonly form a conspicuous proportion of the rock but generally are not so abundant as to form a selfsupporting detrital framework. The matrix is finely crystalline calcite with very subordinate quartz silt. Subtle grain-size differences between discontinuous laminae less than a tenth of a millimeter in thickness impart a faint lamination to the matrix calcite in some thin sections. The sporadically distributed quartz slit in these samples generally corresponds in grain size to the calcite grains of the lamina in which they occur, which suggests that both the calcite and the quartz were deposited as detrital silt-size grains and that the limestone is a calcilutite rather than a recrystallized micrite. In three chemically analyzed samples from the ridge north of Panther Canyon, the amount of SiO_2 ranges from 4 to 11 percent and varies proportionally with the Al_2O_3 content, which ranges from 0.8 to 1.6 percent. Ferric oxide pseudomorphs after fine-grained pyrite cubes are conspicuous in most thin sections; combined values of FeO and Fe_2O_3 range from 0.5 to 1.0 percent. The MgO content ranges from 0.4 to 0.8 percent.

Discontinuous thick beds of grayish-red chert pebbles in a limestone matrix are a characteristic, though minor, constituent near the base of the upper member in all its isolated exposures in the northern part of the range. Also, in contrast with the same part of the section in the southern part of the range, minor amounts of amygdaloidal mafic metavolcanic rocks and some calcareous siltstone are present in the float from the poorly exposed sections at Star Peak and above the Congress Canyon cliffs.

The highest part of the upper member of the Natchez Pass is represented by a few hundred feet of massive gray limestone that underlies the Grass Valley Formation for several miles along the northwest flank of the range and forms the sole of the Humboldt City thrust plate. These limestones are much contorted, sheared, and recrystallized, and they are extensively silicified, probably by hydrothermal activity, particularly toward the south end of their outcrop belt, near the Standard mine.

The third general outcrop area of the Natchez Pass Formation in the Humboldt Range is in the Mill City hills that form the northeastern tip of the range. Here the Natchez Pass occupies the axial region of a major overturned syncline and is correspondingly much contorted and broken. East of Nevada Highway 50 where it crosses the Mill City hills, further disruption of the section has evidently resulted from local landsliding. Despite these complications, a complete section of the Natchez Pass seems to intervene between the exposures of the Prida and Grass Valley Formations, but the character of the formation differs sufficiently from that of the Natchez Pass elsewhere in the range that the same criteria for subdivision into members cannot be utilized. The bulk of the section is thick and very thick bedded massive recrystallized dolomite and limestone interrupted near the middle by a conspicuous unit of coarse- and fine-grained siliceous clastic rocks about 400 feet thick. Within the Natchez Pass below this clastic unit is roughly 1,000 feet of massive gray crystalline dolomite and limestone, and above it, as estimated from the geologic map, is at least several hundred feet of thick-bedded gray limestone intercalated with massive buff-weathering coarsely crystalline dolomite.

Along the south edge of the prominent hill east of State Highway 50, the clastic unit consists of thick and very thick beds of siliceous chert-pebble-and-cobble conglomerate interlayered with siliceous quartz-chert sandstone, argillite, and calcareous siltstone. Weathering of the more argillaceous and calcareous beds produces a distinctive moderate-reddish-brown (about 10*R* 5/6) soil that contrasts strongly with the drab color of the adjacent weathered slopes underlain by massive carbonate rocks. The limited exposure of this clastic unit on the west side of Highway 50 is equally thick but lacks siliceous clastic rocks coarser grained than sandstone and contains correspondingly more interbedded calcareous siltstone and impure limestone, some of which includes abundant shell fragments. This apparent trend for the clastic unit to become more calcareous and to contain increasingly fine-grained siliceous clastic material westward can be observed for only about 2 miles along the strike and hence may be fortuitous, but lateral gradation is at least suggested between this clastic unit and the impure, somewhat silty limestone that forms the lower part of the upper member of the Natchez Pass at Star Peak and elsewhere in the main Humboldt Range.

FOSSILS AND AGE

Identifiable age-diagnostic fossils are scarce in the Natchez Pass Formation despite the prevalence in it of shelly detrital material as a rock-forming constituent. The fossils on which the age of the Natchez Pass is based have been described and illustrated in an earlier paper (Silberling, 1961) and are therefore discussed only briefly here.

The characteristic lower Karnian ammonite *Trachyceras* s.s., has been found about 400 feet above the base of the formation in the northern East Range, and poorly preserved specimens tentatively assigned to this genus and subgenus also occur in limestone intercalated with volcanic rocks several hundred feet below the top of the lower member of the Natchez Pass southeast of Buffalo Mountain at the south end of the Humboldt Range (USGS Mesozoic loc. M657). As upper Middle Triassic fossils occur in the Prida Formation just below the Natchez Pass in both the southern and the northeastern parts of the Humboldt Range, strata of both latest Middle Triassic and early Late Triassic age are probably included in the lower part of the Natchez Pass in these areas. (See fig. 3.) In the northwestern part of the Humboldt Range, however, where lowermost Upper Triassic fossils occur in the underlying Prida Formation, the Natchez Pass must be entirely Late Triassic in age.

A large marine invertebrate fauna, consisting of well-preserved natural molds in partially leached calcareous siltstone, was collected near the stratigraphic base of the siliceous clastic unit that intervenes within the carbonate section of the Natchez Pass Formation in the Mill City hills (USGS Mesozoic loc. M265). Among a variety of pelecypods and cephalopods, the ammonites *Paratropites* cf. *P. sulcatus* (Calcara, of Gemmellaro) and *Spirogmoceras shastense* (Smith) and the pelecypod *Septocardia?* are represented. These two ammonite genera are characteristically late Karnian in age, and pelecypods tentatively grouped under the name *Septocardia* are widely distributed in the Upper Triassic of Nevada and other regions. The same two species of ammonites have recently been found several hundred feet below a fauna characteristic of the *Tropites dilleri* Zone on Vancouver Island, British Columbia (Givens and Susuki, 1963), and they may therefore be indicative of the oldest part of late Karnian time. Several of the pelecypods that occur in the siliceous clastic unit of the Natchez Pass in the Mill City hills (*Septocardia?*, *Alectryonia*, and *Placunopsis*) can also be recognized among the shelly debris in the impure limestone unit that forms the lower part of the upper member of the Natchez Pass in the southeastern part of the Humboldt Range. This faunal similarity lends support to the suggested lateral equivalence of these two lithologically distinctive units within the Natchez Pass Formation in different parts of the Humboldt Range, but definite correlation on the basis of these long-ranging genera is unwarranted.

On the north side of Humboldt Canyon (USGS Mesozoic loc. M1142), fragments of the pelecypod *Halobia* occur in the highest beds of the Natchez Pass Formation; these beds consist of a few feet of impure limestone transitional into the overlying Grass Valley Formation. These specimens have the morphologic features of such species as *H. superba* and *H. ornatissima* that are characteristic of late Karnian strata.

PALEOGEOGRAPHIC INTERPRETATION OF THE STAR PEAK GROUP

Exposures of the Star Peak Group are scattered along nearly the full length of the Humboldt Range, and a section may thus be reconstructed, as shown on plate 2, that illustrates the lateral variation of these rocks in a structurally continuous block that is more than 30 miles long in a north-south direction. Some degree of east-west control on the lateral changes apparent in the Humboldt Range section is provided by comparison with the other principal exposures of the Star Peak Group farther east, in the northern East Range, northern Stillwater Range, and southwestern Tobin Range.

Several different lateral relationships among these rocks can be selected as having especial paleogeographic significance. These are: (1) the lateral variation of the basal part of the Star Peak Group; (2) the interrelation between the massive carbonate rocks of the lower member of the Natchez Pass Formation and the thin-bedded cherty limestone and dolomite of the upper member of the Prida Formation; (3) the relationship between volcanic and carbonate rocks in the lower member of the Natchez Pass Formation; and (4) the regional relations of the upper member of the Natchez Pass Formation.

LATERAL VARIATION AT THE BASE OF THE STAR PEAK GROUP

Upper Anisian ammonite faunas of the *Gymnotoceras rotelliformis*, *G. meeki* or *G. occidentalis* Zones occur in all of the principal outcrop areas of the Star Peak Group, and as these zones occupy 100 feet or less of section, they provide a useful datum below which variations in the basal part of the Star Peak can be compared from place to place. The greatest amount of Star Peak deposition predating these upper Anisian zones took place in the northern Humboldt Range, where as much as 700–800 feet of the Star Peak is of Spathian (latest Early Triassic), early Anisian, and middle Anisian age. Impure calcareous rocks of the lower member of the Prida Formation make up more than 400 feet of this thickness. In the southern part of the Humboldt Range, less than 200 feet of unfossiliferous strata, roughly divided between the lower and middle members of the Prida, underlie the *Gymnotoceras rotelliformis* Zone, and faunas older than late Anisian are not known to occur. The Prida below the upper Anisian ammonite zones in the northern East Range and in the northern Stillwater Range near McKinney Pass is generally similar in composition and thickness to that in the southeastern part of the Humboldt Range. Still farther east, in the southwestern Tobin Range, the Prida is greatly thinned and is represented locally by only a few feet of terrigenous clastics and calcareous sandstone beneath massive carbonate rocks of the Natchez Pass Formation. Here, poorly preserved upper Anisian ammonites occur in the impure calcareous rocks in the basal few tens of feet of the Star Peak Group. On a regional scale, the base of the Star Peak Group is thus generally transgressive southward and eastward away from the northern Humboldt Range.

For the most part, the eroded surface on which the Star Peak Group was deposited had only minor topographic relief, as evidenced by the basal clastic unit of the Prida Formation, which generally contains clasts no larger than pebble size and does not vary in thickness by more than a few tens of feet. In the Humboldt Range, however, some large-scale local topographic irregularities are apparent and evidently have an important genetic relationship to the mineral deposits of the area.

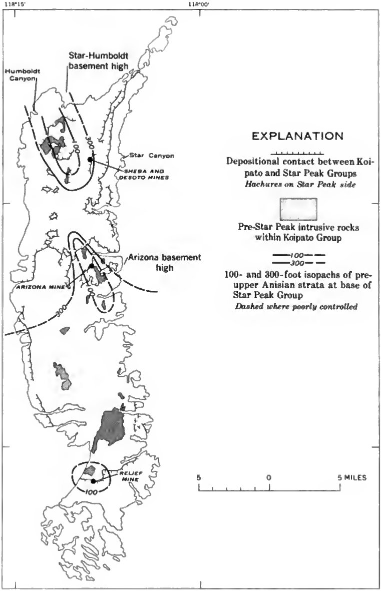
As described previously, abrupt lateral variations in the thickness and composition of the lower member of the Prida Formation in the northern part of the Humboldt Range delineate two distinct basement highs which rose several hundred feet above the adjacent pre-Star Peak erosional surface (fig. 9). The more southern of these, the so-called Arizona basement high, has the shape of an elongate ridge trending somewhat west of north through the Arizona mine area, and it apparently plunges northward toward the forks of Straight Canyon. "Bed-vein" silver deposits (Cameron, 1939, p. 594) like those of the Arizona, Inskip, and Wheeler mines in the lower part of the Prida Formation are apparently localized along the trend of this ridge. Moreover, the position and trend of the Arizona basement high closely coincide with those of the Koipato rhyolite porphyry intrusive rocks that form a string of disconnected exposures from Straight Canyon south to Cottonwood Canyon. In most places, faults separate these silicic intrusive bodies within the Koipato from the adjacent strata of the Star Peak Group; but along the east side of the large exposure of rhyolite porphyry at the head of Peru and Jackson Canyons, small patches of basal Prida Formation rest despositionally on the porphyry, and about half a mile south of the Wheeler mine, the basal Prida is in depositional contact with a small exposure of rhyolite porphyry. Hence, although previously considered of late Jurassic or early Cretaceous age (Cameron, 1939, p. 584), these rhyolite porphyry instrusives clearly predate the Star Peak Group (Wallace and others, 1960).

The Star-Humboldt basement high in the northwestern part of the range is disrupted by several large-scale faults that obscure its configuration. Lateral changes in the thickness of the lower part of the Prida Formation suggest that the east flank of this basement high trends about north-south, roughly on strike with the elongation of the Arizona basement high, but the position of the other sides of the high is poorly controlled. The Star-Humboldt basement high is evidently broader and areally more extensive than the Arizona high. Like the Arizona high, its location coincides with that of a cluster of rhyolite porphyry intrusives within the Koipato that are depositionally overlain by the Star Peak Group; no other intrusive rocks within the Koipato have been found in the northern Humboldt Range north of Unionville. The Sheba and De Soto mines, which were bonanza silver deposits similar in nature and stratigraphic setting to those of the Arizona group of mines, are in the lower part of the Prida Formation in Star Canyon on the east flank of the Star-Humboldt basement high where the lower part of the Prida is partly cut out against the high. The nearest extensive exposures of Koipato rhyolite porphyry are about 1½ miles west of the Sheba and De Soto mines. However, Cameron (1939, p. 602 and footnote) mentioned that the Koipato rhyolite which underlies the basal Prida in the workings of the Sheba mine resembles "granite" porphyry, and he recognized that these porphyrylike rocks are part of the Koipato because of their apparently depositional contact with the overlying basal clastics of the Prida and the absence of contact effects in the nearby calcareous rocks of the Prida Formation.

On Black Ridge, in the southern part of the Humboldt Range, the extreme thinning of the Prida Formation might be due to a preexisting topographic high having accentuated the more general southeastward thinning of the Prida during regional transgression. Here, thinning of the Prida is again associated geographically with Koipato rhyolite porphyry intrusions in the underlying rocks, and the silver deposits of the Relief mine occur in the Prida Formation.

The coincidence in location of topographic highs on the pre-Star Peak surface, intrusive rocks within the Koipato Group, and silver deposits in the basal part of the Star Peak Group strongly suggest a genetic relationship between these three features. The Koipato intrusive rocks, being the oldest of the three, are thought to be the controlling feature. Evidently intrusion of these rhyolite porphyry feeder dikes and related rocks into the Koipato volcanic pile locally affected its resistance to erosion so that the intruded parts of the Koipato were left as topographic highs following the period of tilting or gentle folding and erosion that preceded deposition of the Star Peak Group. The well-

FIGURE 9.—Isopachs of pre-upper Anisian strata at the base of the Star Peak Group plotted on the bedrock outline of the Humboldt Range. Areas of minimum pre-upper Anisian thickness delineate topographic highs on the pre-Star Peak erosional surface of the Koipato Group and coincide geographically with the location of intrusive rocks within the Koipato Group. Traces of the depositional contact between the Koipato and Star Peak Groups are shown to indicate where in the range the basal part of the Star Peak is exposed, and to indicate the control for isopaching its thickness.


118°15'
118°00'
40°30'
40°15'
Star-Humboldt basement high
Humboldt Canyon
Star Canyon
SHEBA AND DESOTO MINES
Arizona basement high
ARIZONA MINE
RELIEF MINE
100
300
EXPLANATION
Depositional contact between Koipato and Star Peak Groups
Hachures on Star Peak side
Pre-Star Peak intrusive rocks within Koipato Group
100
300
100- and 300-foot isopachs of pre-upper Anisian strata at base of Star Peak Group
Dashed where poorly controlled
5
0
5 MILES

defined linear shape of the Arizona basement high seems to relate to the subcrop pattern of the Koipato rhyolite porphyry on the pre-Star Peak surface, but the unique occurrence of mafic volcanic rocks in the basal Prida Formation along the west side of this basement high could also indicate that its shape and topographic relief results in part from block faulting during the initial phase of Star Peak deposition. However, pre-Star Peak faulting within the Rochester Rhyolite would be difficult to demonstrate here because of the heterogeneous, rapidly interlensing lithologic character of these Koipato volcanic rocks, and such faults were not recognized in the course of geologic mapping. Long after the Star Peak Group was deposited, presumably during the time of late Mesozoic intrusive activity, manifested mainly by the granite exposed in the vicinity of Rocky Canyon, the Koipato intrusive rocks evidently served as a source or channel for mineralizing fluids that formed the "bed-vein," stockwork, and replacement silver deposits in the lowest calcareous rocks of the Star Peak Group where they surmount the preexisting basement highs associated with the Koipato intrusive rocks.

FACIES RELATION BETWEEN THE PRIDA AND NATCHEZ PASS FORMATIONS

The upper member of the Prida Formation and the lower member of the Natchez Pass Formation in the Humboldt Range represent a striking change of facies within the Star Peak Group. As already described, the distinctive dark laminated cherty limestone and dolomite of the upper Prida has the form of a thick wedge whose lateral decrease in thickness corresponds to an increase in thickness of the overlying massive carbonate rocks of the lower Natchez Pass (pl. 2). From its northwesternmost exposures in the Humboldt Range, where its thickness may exceed 2,000 feet, the upper Prida thins southward within the Humboldt Range to a wedge edge; to the east, in the northern East Range and near McKinney Pass in the northern Stillwater Range, it thins to only several tens of feet; and in the easternmost section of the Star Peak Group, in the southwestern Tobin Range, it is absent. Inversely, the lower Natchez Pass thickens from only a few hundred feet in the high, northern part of the Humboldt Range to about 1,000 feet toward the northeast in the Mill City hills and to about 1,500 feet toward the south in the southern Humboldt Range (where it contains much volcanic rock besides the more characteristic massive organic-detrital carbonate rock); in the ranges to the east of the Humboldt Range, the part of the Natchez Pass Formation corresponding to the lower member is at least several hundred feet thick.

Partial lateral equivalence of the upper Prida and lower Natchez Pass is demonstrated by their stratigraphic relation to the widespread upper Anisian ammonite zones, which directly underlie the upper member of the Prida, wherever present, or the lower member of the Natchez Pass, where the upper Prida facies is absent, as in the Tobin Range. Within the upper Prida and lower Natchez Pass faunal evidence for contemporaneity is indecisive, but the available faunas strongly suggest that lower Karnian rocks are present in the higher parts of both units in different places. Thick interbeds of massive organic-detrital carbonate rock like that of the lower Natchez Pass are conspicuous in the higher parts of the upper Prida in the Humboldt Range, and though the discontinuity of exposures prevents direct tracing of these beds into the Natchez Pass Formation, they probably represent interfingering of the two facies as shown diagrammatically on plate 2.

The change in facies between the dark, laminated carbonate rocks of the upper member of the Prida and the massive carbonate rocks of the lower member of the Natchez Pass thus takes place within a largely correlative package of Ladinian and lower Karnian strata that thickens from about 1,000 feet on the southeast to more than 2,000 feet to the northwest; and the greatest total thickness corresponds in location to the thickest accumulation of the dark laminated carbonate facies.

Several lines of evidence indicate that the upper Prida is an offshore, relatively deepwater deposit in comparison with the lower Natchez Pass. The lamination and even, thin parting characteristic of the upper Prida points to quiet-water deposition, as do the intercalated chert layers formed of fine-grained biogenic silica. A foul-bottom depositional environment is suggested by the dark color of these rocks and by their lack of a shelly bottom fauna. None of the larger marine invertebrates that occur sporadically as fossils in these rocks is known to have been a bottom dweller. Although quiet-water and foul-bottom conditions are not necessarily restricted to deep basinal environments, an appreciable depth of water is implied by the existence of a paleoslope sufficiently steep to have induced slumping within the upper Prida and the disruptive emplacement in them of coarse sedimentary breccias of massive carbonate rocks. A number of the laterally persistent interbeds of massive organic-detrital carbonate rocks within the dark laminated cherty limestone of the upper Prida were carefully examined for graded bedding or any other features indicative of turbidity current deposition, but nothing conclusive was found.

The depositional environment inferred for the featureless massive medium-gray limestone and dolomite of the lower member of the Natchez Pass is that of a progressively subsiding carbonate bank on which a varied bottom fauna of echinoderms, corals, brachiopods, and mollusks flourished under turbulent shallow-water marine conditions. Although the remains of sediment-binding organisms form a part of the recognizable biogenic calcareous detritus in the lower Natchez Pass, in no place were they seen to form a selfsupporting reef-like framework. Moreover, the progressive and gradual nature of the thickness changes undergone by the lower Natchez Pass precludes the interpretation of any major part of it as an organic reef. This calcareous sand deposit must have accumulated on shallow banks bordering the deeper, more offshore depositional site of the upper Prida on the south and east. But through time, sedimentation evidently exceeded the rate of regional subsidence, and the shallow-water bank deposits of the lower Natchez Pass were gradually built northwestward over previously deposited parts of the upper Prida in a regressive fashion.

The depositional relationship between the upper member of the Prida Formation and the lower member of the Natchez Pass, at least in its broader features, resembles the basinward-shoreward facies changes recognized in some other marine carbonate deposits. Several parts of the lower and middle Paleozoic section of east-central Nevada undergo lateral westward and, in general, basinward change from massive dolomitic carbonate rock to more thinly bedded impure limestone that is commonly laminated and chert bearing. The abrupt facies relations described by Winterer and Murphy (1960) between parts of the Roberts Mountains and Lone Mountain Formations in the Silurian part of this section is particularly pertinent. In composition, environmental interpretation, and spatial relationships these Silurian facies are generally similar to those represented by the upper Prida and lower Natchez Pass. As described by Winterer and Murphy (1960) the fine-grained laminated calcareous rocks of the Roberts Mountains Formation contain a higher proportion of terrigenous clastic material than is found in the upper Prida; the eastward transition of these rocks into massive carbonate rock is more abrupt and is attended by more conspicuous interfingering of sedimentary breccias and graded calcarenites; and organic reefs are thought to be mainly responsible for the thick accumulation of the massive Lone Mountain Dolomite. But these differences in fact or interpretation between the relations of the Roberts Mountains–Lone Mountain facies and the upper Prida–lower Natchez Pass facies are more in degree than in kind, and they do not negate the general paleogeographic analogy.

Also similar to the upper Prida–lower Natchez Pass relationship are some of the basinward-shelfward facies changes in the Permian rocks of west Texas and New Mexico as described by King (1942, 1948, 1962) and further elucidated by Newell, Rigby, Fischer, Whiteman, Hickox, and Bradley (1953). Especially analogous to the lower member of the Natchez Pass is the Victorio Peak Limestone, which is interpreted as a marginal bank deposit of organic-detrital carbonate sand that interfingers with, and was built progressively basinward out over, the partly correlative black cherty laminated Bone Spring Limestone deposited in the marginal parts of the Delaware Basin.

RELATIONSHIP BETWEEN VOLCANIC AND CARBONATE ROCKS IN THE NATCHEZ PASS FORMATION

Volcanic rocks form only a small proportion of the Star Peak Group in the Humboldt Range except in its southwesternmost exposures, where mafic breccias, flows, and tuffs supplant, by abrupt interfingering, most of the massive carbonate rocks of the lower member of the Natchez Pass Formation. The stratigraphic relations of these volcanic rocks are well displayed eastward across Black Ridge and can be interpolated northward, but to the west and south they cannot be determined owing to the absence of outcrops in these directions.

The paleogeographic significance of this volcanic pile in the lower Natchez Pass of the southern Humboldt Range can be interpreted in two ways. It may represent localized recurrent volcanism along what was the shallow southern margin of Star Peak deposition where massive organic-detrital carbonate rock of the lower Natchez Pass was the normal sediment being deposited. Or it may have formed a submarine rise, perhaps emergent at times, on which shallow-water carbonate deposition took place in an area that was relatively offshore with respect to a generally north-south-trending shoreline. The increasing proportion of volcanics in the lower Natchez Pass southward in the same direction that transgression took place at the base of the Star Peak Group in the Humboldt Range tends to support the first of these interpretations. The alternative interpretation is suggested, however, by the abnormally great thickness of the lower Natchez Pass carbonate rocks adjacent to this volcanic pile as compared with their thickness at other places where they overlie a similar section of the Prida Formation but lack thick intercalations of volcanic rocks.

The Natchez Pass Formation exposed to the east of the southern part of the Humboldt Range—near McKinney Pass in the northern Stillwater Range and in the Tobin Range—is closely similar in composition to that which crops out along the southeast edge of the Humboldt Range. The volcanic rocks are generally restricted to a single unit that forms only the uppermost hundred feet or so of the lower member. Recent field studies by R. C. Speed (oral commun., 1963), however, have shown that the area mapped as intrusive rock by

Muller, Ferguson, and Roberts (1951) on the steep east face of the Stillwater Range—from about 10 miles south of McKinney Pass south to Cottonwood Canyon—is underlain, instead, mainly by rocks of the Koipato and Star Peak Groups. The Natchez Pass exposed here was found by Speed to include a much larger proportion of mafic volcanic rocks than it does several miles farther north. Hence, in the northern part of the Stillwater Range, as in the Humboldt Range, volcanic rocks within the Natchez Pass evidently thicken abruptly to the south. Unfortunately, as in the Humboldt Range, this change takes place in the southernmost outcrops of the Natchez Pass, and the nature of the section still farther south cannot be determined. But whether the southward increase in volcanic rocks seen in the Humboldt and Stillwater Ranges represents transition of the Natchez Pass Formation into a widespread volcanic unit, or simply the presence of localized, randomly distributed volcanic piles within a predominantly calcareous section, it constitutes a facies change whose boundary trends northwest-southeast, or about at right angles to the general north-south or northeast-southwest trend of the sedimentary facies-change boundaries within the Star Peak Group that cannot be related to vulcanism. Much of the north to south change from relatively deep-water to shallow-water carbonate deposition displayed by the lateral interrelation between the upper Prida and lower Natchez Pass in the Humboldt Range may therefore relate to the shoaling effect resulting from contemporaneous volcanic activity rather than to the paleoslope controlled by regional subsidence and by the erosional surface of the older rocks over which Star Peak deposition transgressed.

REGIONAL RELATIONS OF THE UPPER MEMBER OF THE NATCHEZ PASS FORMATION

Compared with the underlying parts of the Star Peak Group, the upper member of the Natchez Pass Formation is remarkably consistent in composition throughout the southern part of its regional extent. It is generally the same in the Tobin Range as it is in the southern part of the Humboldt Range; in the northern Stillwater Range it is the same in composition but is thinner. At all these places it rests on volcanic rocks at the top of the lower member of the Natchez Pass, and its lower contact is sharp without noticeable reworking of volcanic material upward into the upper member.

In the high, northern part of the Humboldt Range, the upper member of the Natchez Pass seems to be closely similar to that farther south in thickness and composition, but the incomplete nature of the exposures precludes positive comparison. Farther northeast, in the Mill City hills, however, the corresponding part of the section is different, though it has been suggested in the description of these rocks that the siliceous clastic unit within the Natchez Pass here equates with the impure limestone that forms the lower part of the upper Natchez Pass farther south. If so, an abrupt change in lithology would again mark the base of the member.

Still farther northeast, in the type area of the Natchez Pass in the northern East Range, this chain of lithologic correlations becomes decidedly weaker. Siliceous clastic rocks like those intercalcated with the Natchez Pass carbonate rocks in the Mill City hills here form one or more units as much as a few hundred feet in total thickness in the upper part of the formation, but between them and the overlying Grass Valley Formation is apparently only a few hundred feet of carbonate rock. Assuming a direct correlation of these siliceous clastic rocks with those in the Mill City hills, evaluation of the apparent reduction in thickness of the overlying Natchez Pass carbonate rocks must await more detailed structural and stratigraphic understanding of the East Range exposures. It should be emphasized, moreover, that the greater thickness attributed to the carbonate rocks above the siliceous clastic unit in the northeastern Humboldt Range is little more than a guess and could be seriously in error. Hence, although the upper part of the Natchez Pass in the East Range may relate to that in the Mill City hills, and these rocks may in turn relate to the upper member of the Natchez Pass recognized farther south, positive correlation is not yet possible.

Despite these difficulties in recognizing the upper member in the more northerly outcrops of the Natchez Pass, attention is drawn to the possibility that the upper member disconformably overlies the lower member of the Natchez Pass. This is suggested by the laterally uniform lithologic nature of the upper Natchez Pass in its more southerly exposures and by the sharp contact separating it from the relatively heterogeneous and laterally variable older parts of the Star Peak Group. Furthermore, the faunal evidence is not inconsistent with the existence of a hiatus within the Natchez Pass Formation. The faunas in the lower Natchez Pass and upper Prida that are tentatively dated as earliest Karnian occur only a few hundred feet below the base of the upper member of the Natchez Pass, whereas the late Karnian fauna from the Natchez Pass of the Mill City hills occurs just above the stratigraphic base of the siliceous clastic unit, which may correspond to the base of the upper member. The absence of upper lower Karnian strata may thus be inferred, though biostratigraphic standards in North American are currently inadequate to suggest what proportion of the Karnian this omission might represent.

The decreasing rate of subsidence suggested by the progressive seaward deposition of the shallow-water carbonate rocks of the lower Natchez Pass out over the upper Prida rocks may have culminated in a brief episode of uplift and emergence prior to deposition of the upper Natchez Pass. Rejuvenation of bordering source lands related to this uplift might then account for the coarse-grained terrigenous clastic sediments that appear in the upper part of the formation in its northeastern exposures in the Humboldt Range and in the northern East Range.

GRASS VALLEY FORMATION

The Grass Valley Formation of the Humboldt Range agrees in stratigraphic position, composition, and general thickness with the typical exposures of the formation in the northern East Range (Ferguson and others, 1951). In the Humboldt Range, as in the East Range, the greater part of the Grass Valley is dark argillite, slate, and phyllite interlaminated in part with micaceous siltstone or very fine grained sandstone, all of which characteristically weathers to olive gray or a similar color. Subordinate interbedded units of sandstone as much as several tens of feet thick form occasional dark craggy outcrops on the otherwise smooth, rounded slopes underlain by these rocks. Owing to the lithologically repetitious, poorly exposed, unfossiliferous, and structurally complex natnre of these rocks, their true thickness and detailed stratigraphic succession is indeterminate.

In the northern part of the Humboldt Range the Grass Valley Formation crops out extensively in the low hills along the northwest flank of the range from the Standard mine area north to Imlay Canyon. Along with the highest beds of the underlying Natchez Pass Formation, the incomplete Grass Valley section here forms the upper plate of the Humboldt City thrust and has overridden older parts of the Star Peak Group. Allowing for unrecognized faults and small-scale folds, probably much more abundant than is evident, a few thousand feet is a reasonable estimate for the exposed thickness of the Grass Valley Formation. At the northeast end of the Mill City hills, a few hundred feet of lowest Grass Valley rocks overlie the Natchez Pass Formation in the axial region of a major overturned syncline.

At the southern tip of the Humboldt Range the Grass Valley Formation underlies most of the Pershing mining district and the low hills bordering the south end of Black Ridge. Although both the lower and upper boundaries of the formation are exposed, an indeterminate amount of the section may be cut out structurally. The minimum estimated thickness is about 2,000 feet. Exposures of the lower part of the Grass Valley Formation wrap conformably around the south-plunging anticlinal nose of Star Peak rocks at the south end of Black Ridge from Packard Flat eastward to Cow Canyon. Farther north along the southeast flank of the range, the Grass Valley has been eroded away, but it is preserved beneath the Cenozoic basalt flow between Dry Gulch and American Canyon, where it appears in the underground workings of the Hillside mine.

Much of the Grass Valley Formation exposed in the Pershing district represents the highest several hundred feet of the formation repeated structurally and is atypical in weathering mainly to shades of red or orange and in having some interbedded calcareous rocks. The color difference between this part of the Grass Valley section and the underlying parts is partly a hydrothermal effect, but it may also reflect some primary compositional difference. On strike with the red- and orange-weathering Grass Valley exposures in the Pershing disstrict are similar pelitic and sandy rocks in the small portion of the West Humboldt Range included within the Buffalo Mountain quadrangle, but the full extent of the Grass Valley in the West Humboldt Range is unknown.

The upper contact of the Grass Valley Formation with the overlying carbonate rocks of the Dun Glen Formation in the Pershing district is gradational; the highest argillaceous and sandy beds of the Grass Valley are calcareous in part and include lenticular beds of limestone. On the geologic map, the upper limit of the Grass Valley is arbitrarily placed at the base of the lowest laterally persistent carbonate unit on each of the different strike ridges where the Grass Valley–Dun Glen transitional contact is exposed. As the main body of Dun Glen carbonate rocks probably bears a complex lateral relation to the similar, discontinuous carbonate beds in the uppermost Grass Valley, the formational boundary as drawn probably varies somewhat in stratigraphic level from place to place.

LITHOLOGIC DESCRIPTION

Most of the Grass Valley Formation is formed of metapelitic, silty, and sandy rocks that represent the same general source of sediment supply and differ mainly in the degree of sorting and in metamorphic effects. These rocks are largely noncalcareous and lack interbedded carbonate rocks; exceptions are the highest parts of the formation transitional into the overlying Dun Glen Formation. Terrigenous detrital material coarser than medium-grained sand is absent.

The finer grained pelitic and silty rocks make up two-thirds or more of the section and include slate, phyllite, argillite, and micaceous siltstone. All these rocks are black, or nearly so, in fresh exposures, but weather olive black (5*Y* 2/1) to light olive gray (5*Y* 6/1) and greenish gray (5*GY* 6/1). Commonly all these fine-grained rock types, which differ mainly in the proportion and grain size of their silt content, are mixed together in the finely broken surface debris at any one place. Siltstone is generally distributed as very thin stringers and laminae through the more pelitic rocks, but locally the section may be predominantly slate or phyllite through several tens of feet or more.

The composition of these fine-grained noncalcareous rocks has not been studied rigorously. Judging from the nature of the interstitial material seen in thin sections of the sandstones in association with them, the original clay content of these pelitic rocks has been entirely recrystallized to sericite and chlorite. This is supported by X-ray diffraction analysis of two samples that characterize the extremes in megascopic appearance among the noncalcareous metapelites in the vicinity of Humboldt Canyon. Despite their difference in appearance—one sample is a lustrous dark-olive-gray slate and the other is a "soft" medium- to light-olive-gray silty argillite—their compositions are about the same. Both of them, according to D. B. Tatlock, are about half quartz, with muscovite and chlorite making up the remainder; their total iron content is about 6 percent. The presence of clay is suggested only in the weathered-appearing argillite and can be attributed to weathering.

Sandstones make up about one-third, or less, of the Grass Valley Formation in the Humboldt Range and are chiefly of two different types characterized as "impure" and "clean." To some extent these are intergradational, but intermediate varieties are scarce, and the two different types seem to represent distinct depositional environments.

The impure sandstone is mainly very fine grained—most of the quartz grains in the size range from 0.05 mm (coarse silt) to 0.10 mm (fine sand). Original argillaceous impurity is represented by interstitial sericitic and chloritic material; the chloritic material imparts an olive-gray or greenish-gray color to fresh surfaces of the rock. The pure sandstones, on the other hand, are medium or fine grained and range from nearly white to medium light gray (*N*6) and light brownish gray (5*YR* 6/1) on fresh exposures. Characteristically, their unweathered surfaces are speckled by dark-brown aggregates of ferric oxides and calcite. These calcareous patches may amount to 10 percent or more of some samples, but most of the rock is cemented by interlocking overgrowths of the quartz grains. Apart from their differences in grain size and matrix materials, the impure and clean sandstones are much the same in the mineral composition of their silt and sand fractions. Quartz grains are the most abundant and in the coarser size fractions are moderately well rounded. Albite is present in varying amounts that may be as much as about 30 percent but usually are not more than several percent. No potash feldspar is apparent in the thin sections studied. All the sandstones are conspicuously micaceous; detrital flakes of muscovite form at least several percent of the impure sandstone beds and are concentrated on their internal stratification surfaces, giving them a characteristic spangle. Only a few larger grains of biotite are preserved, and these are in different stages of chloritization. Discrete flakes of chlorite, present in minor amounts in some samples, are probably also a detrital constituent. Heavy minerals are abundant, and in the impure sandstones where their grain size is comparable to that of the quartz, they may constitute a few grains out of every hundred counted. The commonest varieties are a distinctive bluish-green tourmaline, zircon, and opaque grains (largely leucoxene?).

Of the two kinds of sandstone, the impure is the more abundant, and in composition and manner of occurrence it is transitional into the siltstone stringers that are pervasively interbedded among the noncalcareous pelitic rocks. Impure sandstone occurs as very thin or thin even beds either interspersed in the dominantly pelitic section or, more characteristically, grouped together in

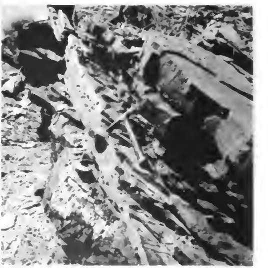


FIGURE 10.—Very thin and thin-bedded impure sandstone of the Grass Valley Formation on the crest of the northern East Range about 1 mile southeast of Dun Glen Park, characteristic of outcrops of this kind of sandstone in both the northern East Range and in the Humboldt Range.

sets with pelitic partings between them (fig. 10). These sets range from a few feet to several tens of feet in thickness and apparently are laterally discontinuous. Even where exposures are good, none could be traced laterally for a distance greater than about 10 times its thickness. Both the lower and upper surfaces of the impure sandstone beds are sharply defined, and the beds show no grading. Small-scale current crossbedding is commonly well developed and expressed on the top surfaces of the beds by linguoid ripple marks (fig. 11). No other kinds of ripple marks are found on these beds. The bottom surfaces commonly bear load casts (fig. 12*C*). More rarely, the bottom surfaces display a profusion of current-formed sole markings of the drag and impact kind, where these markings have not been obliterated by load casts. These "drag," "brush," "bounce," and "prod" marks are invariably associated with the ripplemarked beds and on any one bed indicate the same current direction as that shown by the ripple marks (fig. 13). Thus, the objects that marked the soft bottom on which the sand was deposited may have been carried by the same currents that transported and rippled the sand. Some of the more unusual kinds of sole markings found on the bottom surfaces of these impure sandstone beds of the Grass Valley were illustrated by Dzulynski and Sanders (1962, text-fig. 4; pl. 10, fig. *A*; and pl. 16, fig. *C*).

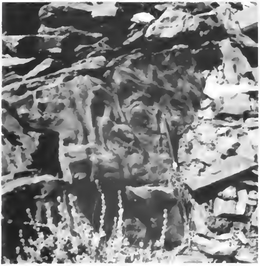


FIGURE 11.—Linguoid ripple marks on the top surface of an impure sandstone bed in the Grass Valley Formation. Pencil point is in the direction of current. Same locality as figure 10.

The slightly calcareous light-colored clean sandstones occur as widely separated discrete units several feet to several tens of feet thick and are most abundant in the higher parts of the Grass Valley section. Unlike the sets of impure sandstone beds, some units of clean sandstone are laterally persistent. Two of them (possibly the same unit repeated structurally), though only 10 feet or so in average thickness, can be traced for more than 1 mile between Humboldt and Imlay Canyons. The clean sandstones are commonly medium bedded and massive appearing, although some planar lamination is usually present within the beds. Oscillation ripple marks were observed near the mouth of Imlay Canyon and in the Pershing district, where the clean sandstones near the top of the formation are commonly crossbedded. These structures provide some of the top and bottom criteria on which the structural interpretation of the Pershing district is based. Of even greater value for this purpose, because of their more widespread occurrence, are load casts formed on the soles of some clean sandstone beds that are intercalated with pelitic rocks in the highest part of the Grass Valley Formation.

The uppermost part of the Grass Valley Formation is repeated several times in the complexly folded and faulted part of the Pershing district southwest of the Relief fault. These rocks differ in appearance from the main body of the Grass Valley elsewhere in the range. Pelitic rocks predominate, as they do throughout the formation, but their weathering colors are chiefly light shades of orange and red, generally in the range from yellowish gray through grayish orange to pale red. Both brittle-fracturing argillites and slates are represented as well as some "soft" flaky "shale." Interbedded in subordinate amounts are clean pinkish-gray (commonly 5*YR* 7/1) calcareous sandstone and discontinuous units of limestone. Some of the limestone is in massive gray beds much like those of the overlying Dun Glen Formation; other units are impure and weather light brown, and some are nodular mixtures of gray limestone in brown calcareous sandstone. Marine fossils occur in the stratigraphically higher of these calcareous interbeds.

Although these deformed upper Grass Valley rocks have a rather large outcrop area, their thickness probably amounts to only several hundred feet. In the upright and apparently continuous Grass Valley section southwest of the anticlinal axis that runs through the Hollywood mine area, the transition from the more characteristic dark metapelites and associated sandstones up into the overlying grayish-orange-weathering pelitic rocks with some interbedded limestone takes place about 700 feet below the top of the formation.

The reason why the pelitic rocks in the Pershing district weather predominantly orange and red, as compared with the dark-olive or greenish-gray color of the pelitic rocks in other parts of the Grass Valley section, is not fully understood from the data at hand. As seen in favorable exposures, such as in mine workings and deep gullies, the orange color results from weathering of originally dark-colored pelite. The few samples of these orange-weathering rocks analysed by X-ray diffraction have kaolin and illite as their principal sheet-structure minerals, whereas the dark-greenish-gray-weathering pelites are chlorite-bearing. Thus, the difference in weathering color may be related to the difference in composition. The chlorite in the dark-weathering pelites, though probably largely recrystallized, must represent some original ferromagnesian constituent such as fine-grained detrital chloritic or biotitic material that was either absent or has been altered in the clay-bearing, nonchloritic, light-weathering rocks. Alteration by pervasive hydrothermal activity is a strong possibility, and in places networks of fractures crosscutting the orange-weathered rocks are bordered by bands of red-weathered rock a fraction of an inch wide, clearly indicating the alteration nature of the orange to red color change.

Nevertheless, some primary compositional control of the light-weathering characteristic is suggested by the essentially stratigraphic nature of its boundaries. Where the transition between dark-weathering and light-weathering metapelites is exposed near the Hollywood mine, it roughly parallels bedding, and in the northwestern part of the Pershing district, dark-greenish-gray slate and argillite forms a distinct stratigraphic unit at the top of the Grass Valley and separates the orange-weathering rocks below from the overlying Dun Glen Formation. Furthermore, orange and red weathering generally coincides with the calcareous part of the section to which marine fossils are restricted in the Humboldt Range and elsewhere, as in the northern Stillwater Range. It seems unlikely that a difference in depositional environment could explain the presence of clays instead of chlorite in these rocks, and this problem remains unsolved. But orange and red weathering might result from some other minor constituent unique to the marine calcareous part of the section—for example, an iron-bearing carbonate mineral that has been removed by subsequent leaching.

At two different localities in the upper Grass Valley Formation of the Pershing district, flute casts (figs. 12*A*, *B*) were found on the soles of thin or very thin beds of somewhat calcareous, but relatively poorly sorted, sandstone intercalated with orange or red pelitic rocks. These are the only known occurrences of these structures in the formation, and as discussed under paleogeographic interpretation, they were formed by currents different from those that deposited the noncalcareous impure sandstones lower in the section.

In the northwestern part of the Humboldt Range, in the Imlay quadrangle, some slate and slaty siltstone of the Grass Valley Formation along the range front immediately north of Humboldt Canyon weathers red-brown (10R 5/4 and similar shades) and includes stringers of calcareous siltstone and very fine grained calcareous sandstone. By analogy with the stratigraphic level of similar rocks in the southern part of the range, these red-weathering calcareous beds may be near the top of the formation.

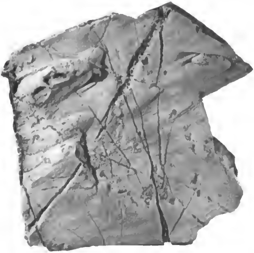
Farther south along the northwestern range front, between Humboldt and Johnson Conyons, the Grass Valley rocks in a belt about 2 miles long and as much as one-half mile wide have been extensively altered, evidently by hydrothermal activity. The eastern boundary of this alteration zone is abrupt and to the north, toward Humboldt Canyon, it apparently coincides with a fault recognized within the Grass Valley Formation. Northward along strike the altered Grass Valley passes into the dark metapelites and sandstones characteristic of most of the formation. Within the altered zone the finer grained parts of the section have been transformed into structureless dense aphanitic rocks that commonly have light-gray and pale-red concentric color banding. In places they are further altered by bleaching and silicification. Sandstone units can be recognized, but the usual metapelitic micaceous and chloritic interstitial material of the sandstone has been altered to ferric oxide and clay.

AGE

Fossils other than traces of plant remains are unknown in the Grass Valley Formation except in its uppermost beds, which are transitional into the overlying Dun Glen Formation, and these occurrences are treated in the discussion of the Dun Glen Formation.

As upper Karnian fauna occur in the upper part of the underlying Natchez Pass Formation and lower middle Norian faunas characterize the uppermost Grass Valley and the Dun Glen Formation, the age of the

FIGURE 12.—Sedimentary structures on the bottom surfaces of sandstone slabs from the upper part of the Grass Valley Formation in the Pershing district at the south end of the Humboldt Range. All reduced to one-half natural size. *A*, Flute casts from locality about one-third of a mile northeast of the Hollywood mine. Current direction toward lower left. *B*, Small-scale flute casts from locality on the south side of South Relief Canyon in the central part of sec. 29, T. 27 N., R. 34 E. Current direction toward lower left. *C*, Load casts from locality about one-tenth of a mile southwest of the Hollywood mine.



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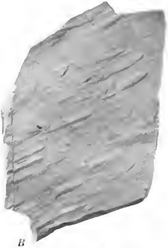

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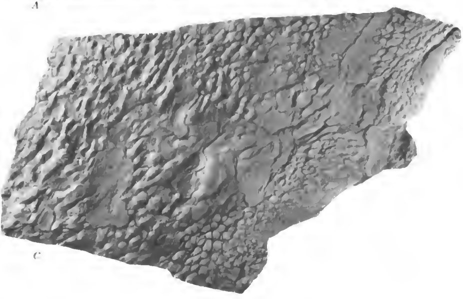


C

Grass Valley is bracketed between fairly narrow limits. It is mainly early Norian in age, but includes strata of early middle Norian age at its top and may include strata of latest Karnian age at its base. (See fig. 3.)

PALEOGEOGRAPHIC INTERPRETATION

The paleogeographic interpretation of the Grass Valley Formation has far-reaching significance because it bears on the depositional history of the much larger, lithologically similar body of strata of which it is a part. The Grass Valley forms the base of a thick widespread assemblage composed mainly of fine-grained terrigenous clastic rocks that range from middle Late Triassic to Early Jurassic in age. These rocks, which crop out at a number of places in Pershing County and eastern Humboldt County, overlie the Star Peak Group and form the upper part of the "Winnemucca sequence" of Silberling and Roberts (1962). Some units of carbonate rock, such as the Dun Glen Formation, occur within this predominantly pelitic and sandy assemblage, but even though their thickness may locally amount to several hundred feet or more, they form only a small proportion of the whole.

In the Humboldt Range and the nearby ranges to the east this assemblage is represented by the Grass Valley, Dun Glen, Winnemucca, and Raspberry Formations and some unassigned strata in isolated exposures. Although an uninterrupted sequence of these formations, which belong mainly to the Upper Triassic, is not preserved, their aggregate thickness is at least several thousand feet. With the addition of similar strata that probably represent higher parts of the section in the West Humboldt Range and Eugene Mountains, the total original thickness of this assemblage in the vicinity of the Humboldt Range was probably much greater.

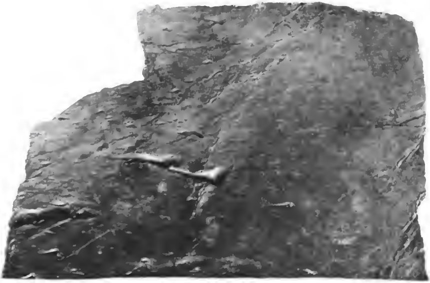
The thickest and most complete known section of these rocks is that described by Compton (1960) in the Santa Rosa Range about 60 miles north-northeast of the Humboldt Range. This section has a thickness of at least 20,000 feet. The lowest exposed part of this section is assigned to the Grass Valley Formation; successively higher units were assigned by him to the Winnemucca, O'Neill, Singas, Andorno, and Mullinix Formations. Except for minor amounts of calcareous and dolomitic rocks, all of this section is composed of metapelitic, silty, and sandy rocks that "had essentially one source and were deposited under similar conditions" (Compton, 1960, p. 1389). The general features recognized by Compton are equally descriptive of the equivalent strata, including the Grass Valley Formation, farther south: (1) pelitic rocks, commonly chloritic metapelites, predominate; (2) the coarser grained detrital constituents are the same throughout and consist of quartzose, somewhat albitic silt and sand, conspicuous amounts of micaceous material, and greater than normal amounts of relatively stable heavy minerals; (3) terrigenous clastic sediment, coarser than medium sand is generally absent; (4) first-cycle volcanic debris is not a significant constituent; and (5) crossbedded rather than graded sandstones predominate, suggesting sedimentary transport mainly by tractional bottom currents. In addition to these generalities, where carbonate units are sporadically intercalated in the section the units commonly bear evidence of shallow-water deposition such as the local abundance of oyster-like pelecypods or the presence of hermatypic corals, coraline algae, or stromatolites.

Regional analysis of specific parts of this thick assemblage is complicated by problems of correlation caused by the lateral and vertical repetition of similar rock types, the structural complexity and metamorphism in some outcrop areas, and the scarcity of age-diagnostic fossils. The Grass Valley Formation, because it is at the base of this assemblage and is locally overlain by the distinctive carbonate rocks of the Dun Glen Formation, is the only terrigenous clastic part of this assemblage that can yet be recognized as a discrete natural unit in several adjacent mountain ranges.

Lateral change within the Grass Valley is pronounced among its principal exposures, which are restricted to either end of the Humboldt Range, the northern East Range, northern Stillwater Range, and the Tobin Range. The thickness of the formation and its composition in terms of the proportions of generalized rock types at these different places is compared in figure 14 by means of pie diagrams. For the more northerly and westerly exposures, where the detailed internal stratigraphy of the formation cannot be determined, these diagrams are only estimates. Nonetheless, they are meaningful for the purpose of gross comparison in view of the strong differences between these exposures and those further southeast.

The easternmost exposures of the Grass Valley Formation are in the Tobin Range, where it is about 1,700 feet thick and consists mainly of light-colored clean calcareous sandstone. Limestone forms a minor proportion and is represented for the most part by one or more

FIGURE 13.—Sedimentary structures of a single slab of thin-bedded impure sandstone from the Grass Valley Formation on the crest of the northern East Range about 1 mile southeast of Dun Glen Peak. Left-right orientation the same for all three views, which are one-half natural size. Current direction generally from left to right. *A*, Smooth bottom surface marked by prod casts and other impact-mark casts. *B*, Sawn surface of cross section, showing current crossbedding. *C*, Top surface bearing linguoid ripple marks.



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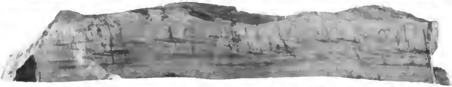

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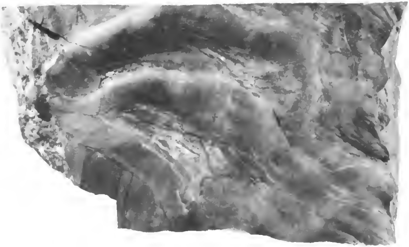

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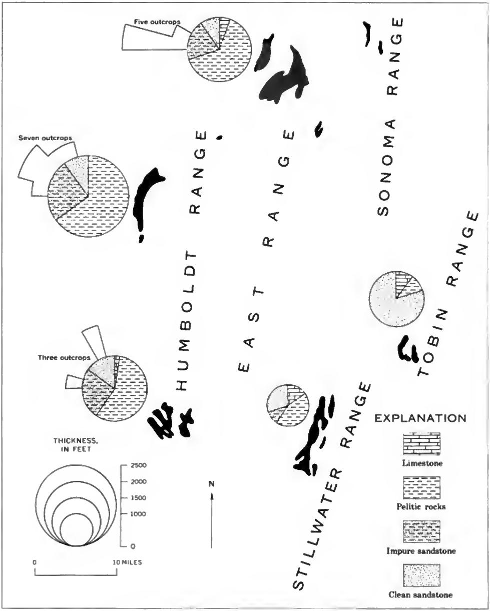

Five outcrops
Seven outcrops
Three outcrops
HUMBOLDT RANGE
EAST RANGE
SONOMA RANGE
TOBIN RANGE
STILLWATER RANGE
THICKNESS, IN FEET
2500
2000
1500
1000
0
0
10 MILES
N
EXPLANATION
Limestone
Pelitic rocks
Impure sandstone
Clean sandstone

units of marine shelly detritus near the middle of the section. Interbedded units of argillaceous rocks are inconspicuous. The predominant sandstone is thick bedded and forms homogeneous units up to a few tens of feet thick that are distinguished from adjacent similar units by subtle differences in grain size, cementation, and bedding characteristics. Large-scale planar crossbedding is characteristic of most beds, and fossil auricarian logs are not uncommon near the top of the formation. The sedimentary environment suggested by these rocks is that of a beach or nearshore marine bar. Similar rocks that are approximately correlative, and evidently were deposited under much the same conditions, are included in the Osobb Formation, whose typical exposures are in the Augusta Mountains about 20 miles south of the Grass Valley exposures in the Tobin Range.

The exposures of the Grass Valley next west from the Tobin Range are in the northern Stillwater Range, where the formation is only about 1,300 feet thick. Approximately the upper half of the section here is similar to the Grass Valley of the Tobin Range in being composed predominantly of well-washed light-colored calcareous sandstone with subordinate interbedded units of limestone and argillaceous rocks. The lower part of the section, however, is noncalcareous pelitic rock with some siltstone and sandstone.

Compared with these exposures in the Tobin and Stillwater Ranges, the Grass Valley Formation in the Humboldt Range and the northern East Range farther west and north, differs greatly in thickness and composition. In these places, it is obviously thicker, although accurate measurement is not possible, and is largely composed of noncalcareous dark-colored pelitic rocks and impure siltstone and sandstone. Clean sandstones are poorly represented, and the minor proportion of limestone is restricted to the highest part of the section. Thus, although it is everywhere largely a fine-grained clastic formation sandwiched between the shallow-water marine carbonate rocks of the Natchez Pass and Dun Glen Formations, the Grass Valley undergoes a nearly complete change in character within a lateral distance of a few tens of miles.

FIGURE 14.—Thickness, composition, and paleocurrent directions of the Grass Valley Formation in the Humboldt Range and nearby ranges to the east. Solid black areas show the map distribution of the principal Grass Valley exposures, for each of which the thickness and composition of the formation is represented by the adjacent pie diagram. Current directions based on sedimentary structures—primarily linguoid ripple marks—of the thin-bedded impure sandstone units are plotted as rose diagrams on the outside of the pie diagrams. The length of each 15° arc on the rose diagrams is proportional to the number of separate observations that fall within that arc.

Impure sandstones of the kind discussed in the description of the Grass Valley of the Humboldt Range are a subordinate, but distinctive, part of the pelitic sections in the Humboldt and East Ranges and are restricted to them. Prevalence of strongly directional linguoid ripple marks is characteristic of these impure sandstones, together with their consistent composition, very fine grain size, and occurrence in discontinuous sets of thin beds. Current directions were determined from these ripple marks wherever possible in the Humboldt Range, as well as in the vicinity of Dun Glen Canyon in the East Range, and are plotted in figure 14 in 15° class intervals as rose diagrams around the peripheries of the pie diagrams for these localities. In general, the orientation of ripples on successive beds shows no perceptible difference, and each observation plotted represents the single current direction estimated visually for all the beds at one locality. In restoring these measurements to the horizontal—in some instances from an overturned position—folding was assumed to have been about horizontal axes. Unfortunately, localities where the bedding surfaces are exposed well enough that the sense of current direction of the linguoid ripples can be estimated directly are few. Nonetheless, the number of observations is sufficiently large, in view of the strong grouping of the observed current directions around a general west-northwest trend, to indicate that their distribution differs from a uniform distribution at a high level of significance. The magnitude of the resultant vector, based on the combined observations from the East Range and northern Humboldt Range, is about 93 percent. This northwesterly current direction is seaward and approximately perpendicular to the shoreline that would be inferred from the general distribution and character of Middle and Upper Triassic rocks in northwestern Nevada.

Also a part of the predominantly pelitic facies of the Grass Valley Formation, though less common than the impure sandstones, are the occasional laterally persistent units of well-washed light-colored sandstone. These clean sandstones tend to be massive but show some primary sedimentary structures—either planar internal lamination or crossbedding related to symmetrical oscillation ripple marks. Where measured in one part of the northern Humboldt Range, the crests and troughs of oscillation ripples, restored to the horizontal about a presumed horizontal fold axis, strike uniformly northeast, or at about right angles to the current direction indicated by the linguoid ripples of the impure sandstone beds in the same outcrop area.

Interpretation of the Grass Valley Formation as part of a near-shore deltaic complex is thought to best fit its combined characteristics and is in context with its role as one part of a much larger assemblage of similar fine-grained terrigenous clastic sedimentary rocks. The relatively thick noncalcareous unfossiliferous pelitic sections of the Grass Valley in the Humboldt Range and northern East Range may represent the lobate part of a delta built westward into the marine basin out beyond the depositional site of correlative shoreline deposits of sandy and calcareous rocks like those that form the Grass Valley in the Tobin Range and the Osobb Formation still farther south and east.

The uniform current direction, lateral discontinuity, and other features of the impure sandstone units within the pelitic facies agree with interpretation of these sandstone units as channel deposits representative of the fluviatile distributary system on the delta surface. Associated units of clean sandstone may be in part beach and bar deposits formed during periods of sorting and winnowing by marine wave action and then incorporated in the muddy section of the delta by its further growth.

The partly calcareous uppermost several hundred feet of the Grass Valley Formation at the south end of the Humboldt Range is interpreted as having been deposited on the submarine slopes of the delta flank during the waning stages of Grass Valley delta building. Sedimentary features shown by the sandstone among these rocks include planar crossbedding, oscillation ripple marks, and, more rarely, flute casts on the soles of nongraded beds. Significantly, current-rippled impure sandstone beds, or the kind found elsewhere in the formation and interpreted as fluviatile channel deposits, are absent. Where measured in two places in the Pershing district, the orientation of flute casts indicates currents that were originally southward. Both flute casts and indications of southward-moving currents apparently are unique to this highest part of the Grass Valley section and may relate to marine depositional conditions.

The foregoing general interpretation of Grass Valley sedimentation implies deposition of the entire assemblage of fine-grained rocks, of which the Grass Valley Formation is a part, along a prograding shoreline. It also implies major river drainage into northwestern Nevada as a source for these sediments. No preexisting thick accumulation of fine-grained clastic sediment that could be readily cannibalized and redeposited was locally available. Nor could local uplift and rapid erosion of the Paleozoic section in western and central Nevada, which includes large proportions of resistent chert, quartzite, and volcanic rock, have yielded the necessary large volume of exclusively fine-grained terrigenous clastic sediment. A more reasonable speculation is that beginning in middle Late Triassic time the drainage from some large portion of the eastern Great Basin, the Colorado Plateau, and Rocky Mountain provinces, parts of which are known to have been alluviated areas of low relief at this time, found access through northern Nevada to the sea. Deltaic deposits, like the pelitic facies of the Grass Valley Formation, may have formed at different times and places as the mouth of a river migrated north and south along the shoreline in northern central Nevada. Sediment thus delivered to the sea was further sorted and spread by marine depositional processes—the result being a thick extensive internally diverse assemblage of pelitic, silty, and sandy rocks.

DUN GLEN FORMATION

The Dun Glen Formation is mainly dark well-bedded massive limestone that forms prominent cliffs and cuestalike ridges in the Pershing district, at the southern tip of the Humboldt range in the Buffalo Mountain quadrangle. It is relatively thin—ranging from several tens to a few hundred feet in thickness—and contains fossils of middle Norian age. Nowhere farther north in the range are strata this high in the Mesozoic section preserved.

At its type locality in the northern East Range, as well as at its other exposures in the ranges immediately east of the Humboldt Range, the Dun Glen Formation is a homogeneous unit of massive dolomite or limestone that separates the Grass Valley and Winnemucca Formations. It is thus a lithologically distinctive entity within a thick section otherwise composed mainly of fine-grained terrigenous clastic rocks. The stratigraphic relations of the Dun Glen in the Humboldt Range are the same, but the overlying beds equivalent to the Winnemucca Formation are not assigned to a named formation.

Within the Pershing district, the thickness of the Dun Glen Formation is 100–150 feet at most places but ranges from as much as a few hundered feet to as little as 50 feet. In comparison, the formation is 500–600 feet thick in the northern Stillwater Range, Tobin Range, and northern East Range and is 1,150 feet thick at its northeasternmost exposure in the Sonoma Range (Muller and others, 1951; Ferguson and others, 1951). Southwestward thinning is thus indicated by these widely scattered outcrops. The Dun Glen Formation apparently also thins northward from its type locality, as it is absent in the Santa Rosa Range according to Compton (1960, p. 1387). Because a persistent relatively pure carbonate unit like the Dun Glen is lacking, Compton placed the contact between his Grass Valley and Winnemucca Formations in the Santa Rosa Range at the lowed limit of the partly calcareous rocks assigned to his Winnemucca. This contact, however, would correspond lithologically to a level within the Grass Valley Formation in sections like those in the southern

Humboldt Range and in the northern Stillwater Range in which the upper part of the Grass Valley is calcareous for an appreciable stratigraphic distance below the Dun Glen Formation. Where the Dun Glen is absent, there is, in fact, no means of recognizing formational boundaries that would precisely correspond genetically to those established in the typical succession of these formations near Winnemucca, and in such areas these formational names probably should not be used.

The Dun Glen Formation in the Pershing district crops out discontinuously along three generally parallel northwest-trending belts that delineate the major structures of the district. Outcrops of the northeastern belt, which extends from Packard Flat southeastward across South Relief Canyon for about 2½ miles where it is truncated by the Relief fault, are in the overturned limb of a major anticline overturned to the northeast. The southwestern outcrop belt parallels the northwestern extension of Pershing Ridge—the ridge along which the Pershing mine is located—but toward the southeast is offset en echelon northeastward and repeated structurally. These Dun Glen exposures are in the overturned limb of a major anticline overturned to the southwest. The central belt of Dun Glen outcrops is areally the most extensive of the three. It includes the exposures that form Juniper Ridge—the ridge on which the Juniper mine is located—and the discontinuous Dun Glen outcrops farther southeast on the same trend. Small-scale contortions abound within the Dun Glye of Juniper Ridge, but, as a whole, the formation in this central belt is upright and on or near the axis of a major syncline on either side of which are major anticlines that are overturned away from it.

To use the Dun Glen Formation as an objective lithologic unit, the authors have assigned to it here only the thickest stratigraphically uninterrupted and laterally persistent predominantly carbonate unit along each of its outcrop belts; stratigraphically higher and lower carbonate beds locally included within the adjacent pelitic and sandy strata are excluded from it. Defined in this way, the thickness and composition of the Dun Glen varies markedly from one outcrop belt to another and even to some extent along the same belt. These variations have no apparent geographic trend and evidently result mainly from rapid intertonguing of the carbonate rocks assigned to the Dun Glen and the enclosing partly calcareous terrigenous clastic rocks.

LITHOLOGIC DESCRIPTION

Medium- to dark-gray massive limestone in well-defined medium to very thick beds characterizes the Dun Glen Formation, but dolomite, intraclastic limestone or dolomite breccia, sandy limestone, and calcareous sandstone are locally well represented. Although bedding within the formation is commonly contorted and the carbonate rocks are much fractured and veined with calcite, recrystallization is generally not megascopically apparent.

Most of the limestone is superficially similar in aspect and is either entirely fine grained in appearance or fragmental with a fine-grained matrix. The matrix consists of very finely crystalline (0.005–0.01 mm) equigranular calcite that has been recrystallized from either a micrite or a calcilutite. Sparry calcite cement is unusual. Allochemical constituents vary widely in abundance, size, and kind. Most common is shelly organic detritus, intraclasts, or mixtures of the two. Other samples that megascopically appear homogeneous prove to be either pelletal or oolitic when viewed in thin section. A few scattered grains of detrital quartz, albite, and muscovite are usually present, and some of the limestone is sufficiently impure to weather brownish gray. Isolated rhombs and scattered patches of secondary dolomite are also commonly seen in thin section, and in places significant portions of the Dun Glen limestone have been altered to finely crystalline dolomite that tends to weather brownish gray or yellowish brown.

Intraclastic limestone or dolomite sedimentary breccia (the "limestone conglomerate" of Bailey and Phoenix, 1944, p. 162–163, 167–168) is a distinctive, though usually minor, part of the formation and intergrades with the finer grained carbonate rocks. It is thickest in the vicinity of the Juniper and Red Bird quicksilver mines, where it forms most of the upper part of the formation and is the host rock for these mercury deposits. Owing to structural complications, most of the Dun Glen cropping out at the Red Bird mine is that part characterized by carbonate breccia, and its thickness is duplicated by faulting. The dolomitic parts of the carbonate breccia have an irregular distribution and are evidently the result of local secondary alteration of limestone breccia. Characteristically, the breccias consist of sand- to pebble-size angular fragments that are rudely stratified by maximum grain size and are so closely packed as to be nearly devoid of matrix (fig. 15*A*). In thin section, the intraclast boundaries appear as pigmented irregular stylolitelike seams along which occur occasional sand-size grains of quartz. This peculiar texture suggests that the clasts of calcareous mud were sufficiently cohesive to be transported and mixed together as angular fragments by currents strong enough to winnow out any finer grained detritus and yet too plastic to maintain a porous rigid framework within which sparry calcite could be deposited. Intraclasts include: a variety of organic-detrital, pelletal, and oolitic dark-gray limestone;

impure argillaceous limestone that weathers pale orange gray or brownish gray; some coarse shelly detritus; and a few clasts of calcareous siltstone and sandstone. Gray- and brown-weathering interclasts are about equally abundant and give the breccia a distinctive mottled appearance. Some laminated brown- and gray-weathering sandy limestone is interbedded with the breccia, and some brecica, particularly that locally present at the base of the formation, consists of poorly sorted limestone intraclasts sparsely scattered in impure sandy limestone.

In general, the Dun Glen sections in the Pershing district that are composed mainly of dense gray bedded limestone are the thinnest. The northeastern outcrop belt, which crosses South Relief Canyon, is entirely bedded gray limestone and only about 50 feet thick, though it is paralleled in part by an equal thickness of similar limestone in the upper part of the stratigraphically underlying Grass Valley Formation. The Dun Glen outcrop belt that parallels Pershing Ridge is mainly bedded gray limestone also, and its thickness varies from about 150 feet to several tens of feet—apparently it thins northwestward by interfingering with calcareous sandstone. At the southeast end of the outcrop belt that follows the trend of Juniper Ridge, near the Hollywood mine, the formation is 100–150 feet thick and consists of bedded gray limestone with some discontinuous interbeds of calcareous sandstone. Northwestward along this outcrop belt the thickness of strata included in the Dun Glen increases to at least a few hundred feet near the Juniper mine, mainly by the addition of sedimentary breccias to the upper part of the formation. Though these breccias intergrade with the limestone and are inseparable from them as a map unit, they might originally have been an interbedded succession of limestone and fine-grained terrigenous clastic rocks like that which immediately overlies nearby sections of Dun Glen limestone. By differential reaction to strong wave action or other currents, the limestone may have been concentrated as a coarse clastic deposit and the originally interbedded fine-grained terrigenous sediment been swept away. Thus, the anomalous thickness of the Dun Glen section here might have resulted from the local formation of limestone breccia in place or nearly so.

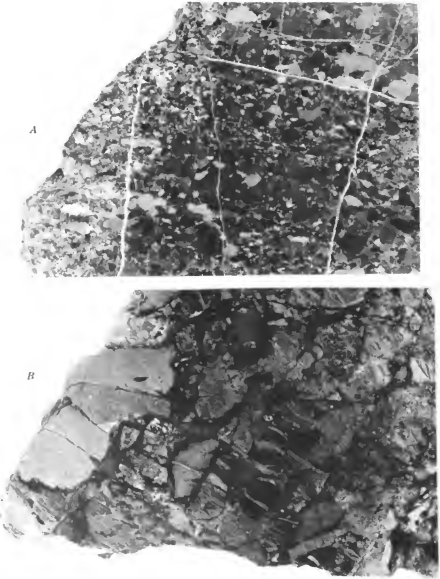
FOSSILS AND AGE

The limestones of the Dun Glen Formation and the calcareous beds in the immediately underlying strata locally contain an abundance of marine fossils. Few of these fossils are of much value for precise age determination, but many of them, such as hermatypic corals, coralline algae, and thick-shelled oysterlike pelecypods, are of considerably importance as indicators of extremely shallow marine depositional conditions. Fortunately, a few diagnostic middle Norian ammonites have also been found that provide a firm basis for dating these rocks in the Humboldt Range and, by lithologic correlation, for assigning an age to the equivalent part of the section in nearby ranges.

The most fossiliferous locality, originally discovered by Prof. S. W. Muller of Stanford University, is about half a mile south of the Juniper Mine (USGS Mesozoic loc. M96) and along strike, in the calcareous, argillaceous, and sandy strata just below the Dun Glen Formation and above a thick lense or tongue of massive organic-detrital limestone in the Grass Valley Formation. Included in the large and varied assemblage from this locality are the ammonites *Indojuvavites* cf. *I. angulatus* (Diener) and *Arcestes*; the nautiloids *Clydonautilus* cf. *C. noricus* Mojsisovics and *Paranautilus*: "*Alectryonia*," *Lima*, *Cassianella*, *Minetrigonia*?, *Septocardia*? nuculid, mytilid, megalodontid, and other pelecypods; *Plectoconcha aequiplicata* (Gabb), *Spondylospira*?, and other brachiopods; indeterminate molds of large gastropods; echinoid and crinoid debris; colonial corals of several kinds; *Heptastylis* and other spongiomorphs; and *Solenopora*-like algae. Except for the cephalopods, for which this particular locality is unique, this same assemblage, commonly with the addition of the pelecypods *Pinna* and "*Trichites*" and blocks of anricarian wood, occurs either in or just below the Dun Glen Formation at a number of other places in the Pershing district and in the northern Stillwater Range and Tobin Range. *Plectoconcha aequiplicata* (Gabb) was originally described from the northern Stillwater Range, presumably from these beds to which it is restricted and in which it is common.

Two other occurrences of ammonites in the Pershing district are in the partly calcareous upper Grass Valley Formation that forms the core of the faulted overturned anticline between Pershing and Juniper Ridges. Flattened impressions questionably identified as *Indojuvavites* cf. *I. angulatus* occur at USGS Mesozoic locality M1188 in impure limestone a few hundred feet below the Dun Glen Formation in the overturned limb of the anticline and at a stratigraphic level comparable to that of locality M96, where this species occurs in the up-

FIGURE 15.—Carbonate breccia and conglomerate from Upper Triassic rocks of the Pershing district in the southern Humboldt Range. Photographs only slightly reduced from natural size. *A*, Sawn surface of limestone sedimentary breccia from the upper part of the Dun Glen Formation on Juniper Ridge about a quarter of a mile northeast of the Juniper mine. *B*, Weathered surface of dolomite conglomerate from the lower part of the lower unit of post-Dun Glen strata on Pershing Ridge near the Pershing mine.


A
B

right, northeastern limb. At an apparently lower stratigraphic level closer to the anticlinal axis, at USGS Mesozoic locality M1191, are ammonite impressions with distinctive ornamentation like that of *Pterotoceras caurinum* McLearn.

A single specimen of *Juvavites magnus* McLearn was collected from USGS Mesozoic M664 within the Dun Glen Formation at the northwest end of Pershing Ridge; it was in association with large-sized megalodontid pelecypods. North of South Relief Canyon, at USGS Mesozoic locality M1187, a large specimen of *Metacarnites* was found, also within limestones of the Dun Glen Formation.

Though limited in variety, the ammonites from the Dun Glen and the immediately underlying part of the Grass Valley Formation can be dated within fairly close limits by comparison with the Upper Triassic faunal succession of the Pardonet Formation in the Peace River Foothills of northeastern British Columbia established by the late F. H. McLearn (1960). *Juvavites magnus* is the nominal index species for the zone, among those zones erected by Tozer (1965a) for McLearn's succession, that is regarded as the lowest faunal subdivision of the middle Norian in North America (Silberling and Tozer, 1968). In the Peace River Foothills, *Pterotoceras caurinum* also occurs in the *J. magnus* Zone. *Metacarnites* has been found in place in northeastern British Columbia only in the next higher *Drepanites rutherfordi* Zone, which represents the middle part of the middle Norian. *Indojuvavites* cf. *I. angulatus* was also recorded from the Pardonet Formation by McLearn (1960, p. 18, 92), but from an unknown stratigraphic level.

In summary, on the basis of fossil correlations, the Dun Glen Formation and the calcareous rocks that form the highest part of the underlying Grass Valley Formation in the Pershing district represent the lower part, and perhaps also the middle part, of the middle Norian substage.

POST-DUN GLEN LOWER MESOZOIC STRATA IN THE PERSHING DISTRICT

The lower Mesozoic strata that succeed the Dun Glen Formation in the Pershing district, at the southern tip of the Humboldt Range, include a variety of partly calcareous fine-grained terrigenous clastic sedimentary rocks and some interbedded carbonate rocks. Most of these are Late Triassic in age, but some are Early Jurassic. These rocks are largely confined to the low ridges and hills in the southern and southwestern parts of the Pershing district and to the adjacent isolated outcrops that protrude from beneath the veneer of lacustrine and alluvial deposits along the margins of Antelope Valley and the Carson Sink.

Except for the beds immediately overlying the Dun Glen Formation, the limited extent and discontinuity of exposures of these structurally complicated rocks preclude determination of their stratigraphic succession in any detail. However, on the basis of lithologic differences and paleontologic evidence, the younger of these rocks can generally be separated from the older; hence, their various outcrops are apportioned on the geologic map between a "lower unit" and an "upper unit," although the stratigraphic relation between these two informal units is uncertain. In sections 16 and 17, T. 26 N., R. 34 E., southwest of Pershing Ridge, isolated exposures of the two units parallel one another concordantly for a strike distance of about 1 mile; the two units appear to be in normal depositional sequence. Nevertheless, owing to their limited areal extent and incomplete exposures, little useful purpose would be served by establishing formally named lithologic units here. They are lithologically similar, partly correlative, and probably genetically related to the Winnemucca Formation (Muller and others, 1951) and the Raspberry Formation (Ferguson and others, 1951) which were named for exposures in the Sonoma Range and the northern East Range respectively. These formations, however, cannot be readily recognized away from their typical outcrops because, as defined, they are neither unique in lithologic composition nor bracketed by distinctive stratigraphic boundaries.

LOWER UNIT

The lower unit of post-Dun Glen strata in the Pershing district includes the beds that depositionally overlie the Dun Glen Formation. In most places as much of the section as is exposed forms a fairly homogeneous unit; here, younger beds, which are distinctive elsewhere, have been eroded or faulted away.

Some of the lower unit overlies the Dun Glen Formation along all three of its outcrop belts in the Pershing district. More than 1,000 feet of the lower unit is exposed in the overturned section between the northeastern belt of Dun Glen and the Relief fault. These rocks are essentially like the highest part of the Grass Valley Formation, from which they are separated only by the relatively thin Dun Glen Formation. They consist of highly fractured partly silty argillite that weathers yellowish brown, light brown, or pale red, and subordinate interbedded clean light-colored sandstone. From a distance, the weathered slopes are grayish orange with streaks of light gray produced by the sandstone units that are unevenly distributed through the section. Sandstone forms only several percent of the total thickness and rarely forms units more than a few feet thick. Much of it is crossbedded, and in places well-formed oscillation ripple marks are preserved.

Along their central belt of exposures, the contorted and intricately faulted Dun Glen carbonate rocks are locally overlain by as much as a few hundred feet of red-weathering argillaceous rocks. The contact between these rocks of the lower unit and the Dun Glen was explored by the principal workings of the Juniper and Red Bird (Antelope Springs) mines (Bailey and Phoenix, 1944, p. 162–167).

The most extensive exposures of the lower unit of post-Dun Glen rocks border the southwestern belt of Dun Glen outcrops on their southwest side. All of the beds in these exposures are overturned, and they are separated by a concealed fault, trending northward through the east edge of secs. 10 and 15, T. 26 N., R. 34 W., from isolated ridges of the same strata in an upright position at the southeast end of the synclinal belt that follows Juniper Ridge. The lower unit of post-Dun Glen strata in the southern and southeastern Pershing district is formed mainly of fine-grained terrigenous clastic rocks that weather to light, moderately saturated, yellow-red hues; in contrast with the sections in the northwestern part of the district, it includes a conspicuous ridge-forming unit of dolomite conglomerate in its lower part. This distinctive unit caps Pershing Ridge; and several shorter, subsidiary ridges that parallel the southeast end of Pershing Ridge owe their existence to structural repetition of the dolomite conglomerate. A few hundred feet of red-weathering partly silty argillaceous rocks separates the northwest-dipping strike ridges of dolomite conglomerate from those of the stratigraphically lower, massive carbonate rocks of the Dun Glen Formation, so that where not complicated by strike faulting, these two carbonate units of differing character form a couplet with similar topographic expression.

Possibly the dolomite conglomerate on Pershing Ridge correlates with the sedimentary breccia of carbonate rocks that forms the upper part of the Dun Glen Formation on Juniper Ridge and accounts for the anomalously great thickness of the formation there, but discontinuity of exposures precludes tracing the two together. It is noteworthy, however, that the principal quicksilver deposits in the district are restricted to these two rock types, which are at least approximate lateral equivalents.

The dolomite conglomerate of Pershing Ridge ranges in thickness from 10 to about 100 feet, the more southeasterly exposures being the thickest. It is massive and homogeneous except for crude stratification resulting from variation in the size of the clasts, which are mostly less than 2 inches in diameter but range up to 16 inches in greatest dimension. Most of the clasts are subangular to subrounded dolomite that displays a variety of different textures and ranges in unweathered color from dark gray to grayish orange. Other clasts include light-brown dolomitic siltstone and, more rarely, chert. Sorting is poor, and the conglomerate clasts are closely packed; grayish-orange dolomitic sandstone fills the interstices between them. A representative slab is shown in figure 15*B*. Throughout the extent of its outcrops, the carbonate components of this unit are wholly dolomitic. As the carbonate rocks of the Dun Glen Formation a short distance stratigraphically below the dolomite conglomerate are calcareous and the terrigenous clastic rocks stratigraphically just above it are partly calcareous and include some interbedded limestone, dolomitization of the conglomerate was remarkably selective and hence perhaps diagenetic. This stratigraphic selectivity of dolomitization might also relate to a relatively high permeability of the conglomerate with respect to secondary mineralizing fluids—a factor that may be of significance in explaining the localization in this unit of the quicksilver deposits along Pershing Ridge. Other factors, however, such as the fracturing of the dolomite conglomerate unit due to its difference in competency from the enclosing pelitic rocks, have no doubt also influenced mercury mineralization.

Near the Pershing mine, where exposures are better than in most places, the dolomite conglomerate is stratigraphically overlain by up to several feet of well-sorted grayish-orange limy sandstone that is in turn overlain by several tens of feet of poorly bedded brown-weathering dark-gray sandstone. The grayish-orange ("buff-colored") unit, where present at the stratigraphic base of this sandstone sequence, formed a useful marker bed in the underground mercury-mine workings and is reported to be interbedded with the stratigraphically upper part of the dolomite conglomerate farther east along Pershing Ridge (Bailey and Phoenix, 1944, p. 166). Stratigraphically higher parts of this overturned section, above the dark standstone, are mainly flaky, finely fractured pelitic rocks ("shale"); a few feet of impure limestone occurs about 150 feet stratigraphically above the dolomite conglomerate.

About 2,000 feet southwest of Pershing Ridge, the dolomite conglomerate unit is repeated by a steeply dipping, apparently normal fault, and it is intermittently exposed as a vertically dipping rib that strikes through the SE¼ sec. 8 and the NW¼ sec. 16, T. 26 N., R. 34 E. Between these outcrops of the dolomite conglomerate and the parallel belt of *Monotis*-bearing calcareous strata assigned to the upper unit of post-Dun Glen rocks farther southwest, the poorly exposed section of the lower unit is monotonously the same and consists of orange- and light-brown-weathering partly silty argillaceous rocks with minor amounts of intercalated brown sandstone. These beds are either vertical or steeply overturned to the southwest, and, if unfaulted, this section of the lower unit above the dolomite conglomerate unit is about 2,000 feet thick.

For the most part, fossils are absent in the lower unit of post-Dun Glen strata. At an isolated exposure several hundred feet south of the southeastern tip of Pershing Ridge (USGS Mesozoic loc. M663), however, a large ammonite fauna was obtained from a few closely associated loose blocks that were evidently derived from a single highly fossiliferous bed. Included in this fauna are:

Himavatites columbianus McLearn
"*Dittmarites*" aff. "*D.*" *lilli* (Guembel)
Distichites sp. [immature specimens only]
"*Sandlingites*? sp." of McLearn (1960)
Pseudosirenites pardoneti (McLearn)
Helictites decorus McLearn
Helictites cf. *H. subgeniculatus* Mojsisovics
"*Parajuvavites*" sp. [similar to "*Parajuvavites* sp." of McLearn (1960)]
?*Episculites* cf. *E. terres* (McLearn)
Placites sp.
Arcestes sp.

All these ammonites, except "*Dittmarites*" aff. "*D.*" *lilli*, are either conspecific with or closely related to those described by McLearn (1960) from the beds in the Peace River Foothills of northeastern British Columbia. The ammonites are typical of the *Himavatites columbianus* Zone of Tozer (1965a), which is regarded as late middle Norian in age (Silberling and Tozer, 1968).

If this isolated fossil locality is projected into the overturned section of the lower unit of post-Dun Glen rocks on the southwest side of Pershing Ridge, it falls at a horizon within a few hundred feet stratigraphically above the dolomite conglomerate unit. As a concealed fault of significant displacement could easily exist between this locality and the continuous exposures of the lower unit on Pershing Ridge, the stratigraphic position of this critical ammonite fauna would be only speculative were it not for a single well-preserved specimen assignable to *Distichites* cf. *D. mesacanthus* Mojsisovics found by Prof. S. W. Muller on the southwest slope of Pershing Ridge just west of the Pershing mine furnace (about 1,400 ft north of the SE. cor. sec. 8, T. 26 N., R. 34 E.) at a stratigraphic level about 300 feet stratigraphically above the dolomite conglomerate unit. As far as is known, *Distichites* is restricted to the *Himavatites columbianus* Zone in North America, and species similar to that represented by Professor Muller's specimen were described by McLearn (1960) from the *H. columbianus* Zone of Northeastern British Columbia.

The lower part of the lower unit of post-Dun Glen rocks can thus be independently dated on the basis of faunal evidence as late middle Norian. As these rocks are in stratigraphic succession with the Dun Glen Formation, which contains fossils of early middle Norian age, the faunal evidence confirms the structural interpretation whereby the Grass Valley, Dun Glen, and post-Dun Glen rocks in the vicinity of Pershing Ridge are all regarded as overturned. The upper age limit of the lower unit of post-Dun Glen strata is restricted by the occurrence of upper Norian fossils in the overlying strata assigned to the upper unit of post-Dun Glen rocks.

At least the lower part of the lower unit of post-Dun Glen strata in the Humboldt Range is equivalent to the Winnemucca Formation in the nearby ranges to the east, where the Winnemucca overlies the Dun Glen Formation but lacks a stratigraphically defined upper limit. No age-diagnostic fossils have been found in the Winnemucca Formation and hence the best evidence for its age is the occurrence of the upper middle Norian *Himavatites columbianus* Zone at a stratigraphically analogous position in the Pershing district section. The Karnian age suggested for fossils from the so-called Winnemucca Formation of the Santa Rosa Range by Compton (1960, p. 1387) is almost certainly wrong, provided that the lithologic correlation of these beds with the type Winnemucca Formation of the Sonoma Range is correct.

UPPER UNIT

Exposures assigned to the upper unit of post-Dun Glen strata are restricted to an area of about 2 square miles in the southernmost part of the Pershing district, where they occur mostly in scattered structurally discordant outcrops separated from one another by Quaternary deposits. Lithologically they are heterogeneous and include a variety of interbedded sedimentary rocks—calcareous siltstone and sandstone, impure limestone, siltstone, and pelitic rocks—no one of which dominates more than a few hundred feet of section. Compared with the lower unit of post-Dun Glen strata, the upper unit includes proportionally more sandy and calcareous rocks. Pelitic rocks appear to be subordinate in the upper unit, though this appearance is probably due in part to their nonresistant, poorly outcropping nature.

The thickest apparently uninterrupted partial section of the upper unit is in north-central sec. 17, T. 26 N., R. 34 E. Here the upper unit appears to rest conformably on the lower unit of post-Dun Glen strata; more than 1,000 feet of the upper unit is exposed and dips moderately to steeply southwest in an upright position. In ascending order, the following units are represented:

1. Brown- and yellow-brown-weathering sandstone, partly calcareous, with lenticular interbeds of dense black, orange-brown-weathering, silty limestone; estimated thickness a few hundred feet; *Monotis subcircularis* Gabb locally abundant, as at USGS Mesozoic locality M1667.
2. Finely fractured argillite, olive-gray or brown, with interbeds of laminated siltstone; about 300 feet thick.
3. Calcareous very thin bedded siltstone, with subordinate silty limestone; about 200 feet thick.
4. Massive gray partly dolomitic limestone; partly conglomeratic; stromatolitic at top; about 100 feet thick.
5. Calcareous siltstone; very thin bedded; weathers pale red, light brown, or medium gray; exposed thickness a few hundred feet.

Fossils are fairly common in the upper unit and are widely enough distributed to be useful in identifying isolated exposures as belonging to this map unit. As the upper Norian pelecypod *Monotis subcircularis* Gabb is especially characteristic, the beds herein assigned to the upper unit of post-Dun Glen strata were informally designated the "beds containing *Monotis*" on the preliminary geologic map of the Buffalo Mountain quadrangle (Wallace and others, 1959). In addition to its occurrence at USGS Mesozoic locality M667, and along strike, *M. subcircularis* is found at and near USGS Mesozoic locality M658 and at other places not plotted on the geologic map. Isolated fossiliferous exposures in the SW¼ sec. 17, the NW¼ sec. 20, and the N½ sec. 21, T. 26 N., R. 34 E., evidently represent the lower parts of the upper unit of post-Dun Glen strata repeated by concealed faults. Some of these exposures consist of only a few square feet of outcrop surrounded by lacustrine deposits of Pleistocene Lake Lahontan and encrusted with calcareous tufa. Locally in these isolated exposures, such as at USGS Mesozoic locality M660, *Monotis subcircularis* is found associated with the ammonites *Placites*, *Rhabdoceras*, and *Sandlingites*? From this and nearby isolated localities, Prof. S. W. Muller, of Stanford University, collected, in addition to these forms, the ammonites *Pinacoceras* cf. *P. rex* Mojsisovics, *Sagenites* cf. *S. giebeli* (Hauer), *Metasibirites*, and *Arcestes*. All these faunas are indicative of the upper Norian *Rhabdoceras suessi* zone of Silberling and Tozer (1968) and Tozer (1967).

Isolated outcrops of limestone northwest along strike from the stromatolitic limestone unit in the section itemized above locally contain (as at USGS Mesozoic loc. M670), an abundance of pelecypods closely similar to *Pecten tyaughtonae* McLearn, which in southwestern British Columbia is part of the upper Norian pelecypod fauna of the Tyaughton Group (McLearn, 1960, p. 37).

In addition to these occurrences of upper Norian fossils in the upper unit, Lower Jurassic fossils occur about 1 mile south of the southeast end of Pershing Ridge at two closely spaced but isolated localities, USGS Mesozoic localities M662 and M669. From the former, *Pseudotropites* cf. *P. ultratriassicus* (Canavari) and other ammonites whose closest resemblance is to *Franziceras*-like psiloceratinids were collected along with stylophyllid solitary corals, gastropods, and a variety of indeterminate pelecypods from silty brownish-gray partly conglomeratic limestone. These fossils occur as broken coarse-clastic debris and are associated with granules and pebbles of siltstone. The ammonites indicate an Early Jurassic age no younger than early Sinemurian.

From the nearby locality M669, which is less than 200 feet northeast from locality M662, *Harpoceras*-like hildoceratid ammonites of Toarcian age were collected from thin-bedded impure limestone and calcareous siltstone in another small isolated exposure. The explanation for the geographic proximity of these two faunas of widely different age within the Lower Jurassic is not certainly known, and their relations are obscured by the lack of exposure between the fossil localities. As the beds in which they occur dip northeast, and they are thus apparently in their proper stratigraphic sequence, a disconformity could separate the two. Alternatively, the older fauna could have been reworked, or, more likely, a concealed fault may intervene between them. A concealed fault is probably also required northeast of loclaity M669 between it and the nearby ridge of northeast-dipping massive limestone that resembles the stromotolitic unit in the more complete section about 2 miles farther west.

Impure conglomeratic limestone resembling that at locality M662 and perhaps also of Early Jurassic age, forms another small isolated outcrop about 1 mile southwest of locality M662.

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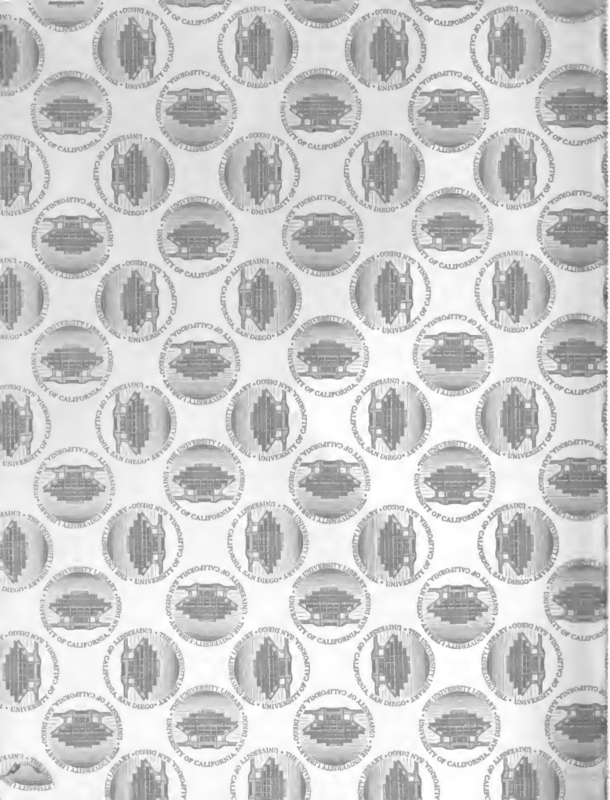
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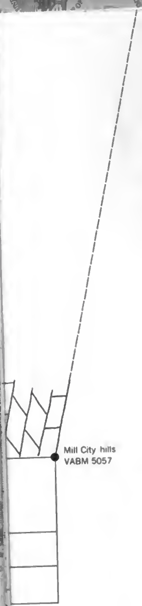
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